Development of Chip Size Monitoring System in Deep-Hole Machining

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Abstract

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This investigation concerns with the metal chip size monitoring method in deep-hole machining process. Monitoring and control of the chip size and shape is very important in deep-hole machining because a visual monitoring is obstructed by hidden chip passages. Yet, for the process, any chip size which may result in passages clogging will result in a failure of machining process. In this manufacturing process monitoring system, the three principal components for chip status monitoring have been investigated: the sensing chip concentration, the signal processing, and the classification (decision making). A new sensing system and monitoring method have been investigated and proposed for use. An inductive proximity sensor was selected and used for data acquisition (sensing), and a personal computer utilized for signal processing. As a monitoring method, the expert system of deep-hole machining control has been suggested for decision making based on the sensing system signal. The experimental testing has revealed that the sensing system signal is strong enough to be used for the machine tool control.

Acknowledgement

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List of Figures

List of Tables

Tables **Page**

Nomenclature

a_t	noise
h	process condition
i	the variation of the monitoring indices
j	the variation of the process conditions
k	the variation of the learning samples
n	seconds
P	operator
Q	relationship
t_r	threshold value
T	set of time instances
W	signal alphabet
x	monitoring index
y	sensor signal
y_t	sensor signal
Φ_t	parameter matrices
θ_t	parameter matrices
x_n	mean of frequency over n seconds
y_1	sensor signal

Table of Contents

Chapter 1 Introduction of Deep-Hole Machining with Expert Control System

Chapter 2 Chip Size Monitoring - Experimental System

Chapter 3 Monitoring Methods

Chapter 4 Analysis of Experimental Results

Chapter 1

Introduction to Deep-Hole Machining

The demands of the modern industry require continuous development in manufacturing involving a higher complexity, higher precision, and higher degree of automation in order to improve quality, to increase efficiency, and to reduce production cost. Machining, or metal removal, is a very important process of manufacturing activities.

The Deep-Hole Machining is considered one of the key technologies in this area because of its unique machining characteristics. The deep hole machining process has evolved continuously in term of both the machine tool and the tools to meet the ever-increasing requirements. This has resulted in development of special purpose deep hole drilling machines. The principle of BTA deep hole machining is illustrated in **Figure 1-1** [1]. In fact, most machining problems that one needs to resolve in practice are associated with the automation and intelligence of the machining process [2].

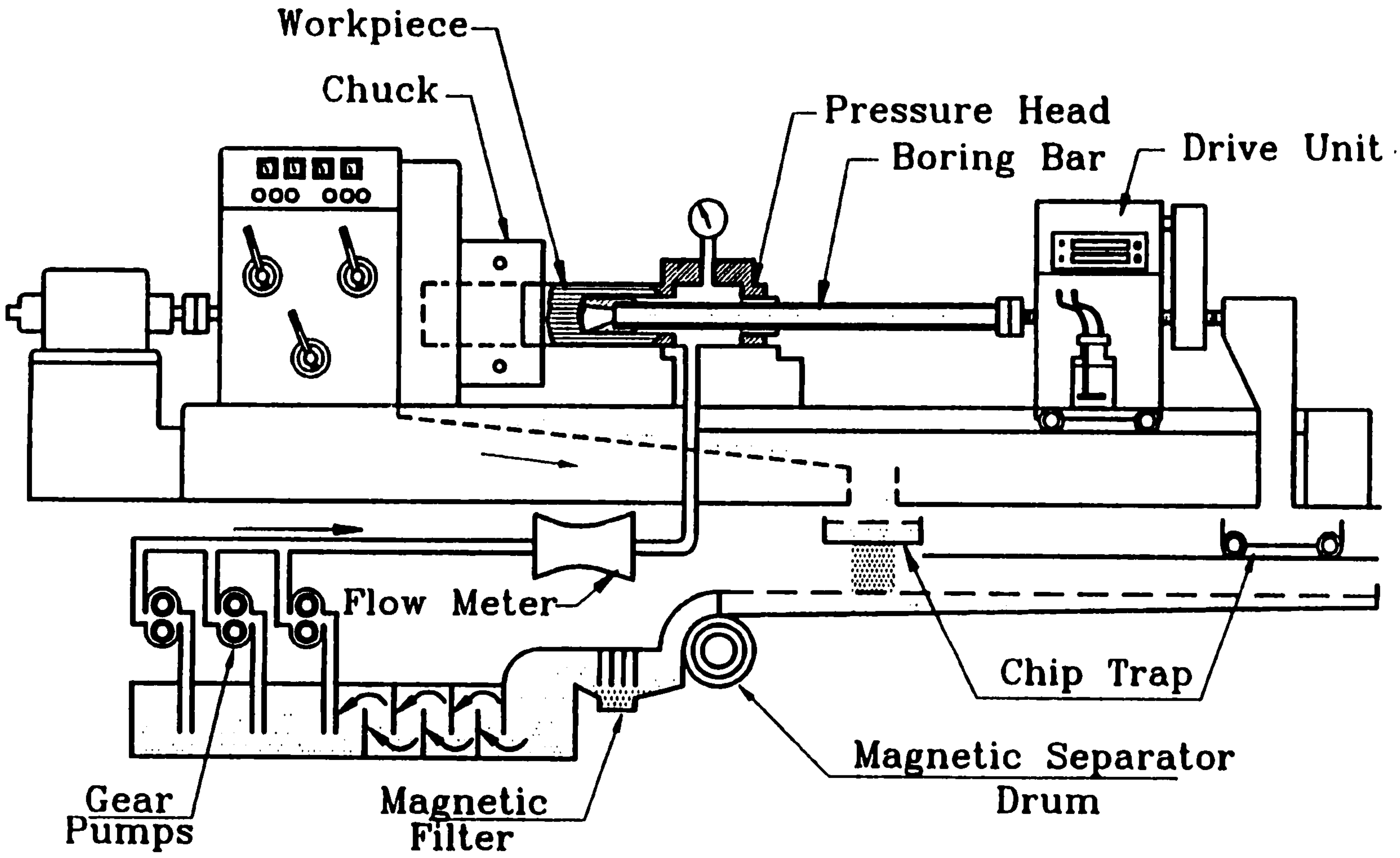


Figure 1-1 Principle of BTA deep-hole machining

1.1 Deep Hole Machining Systems

The machining of holes of high length-to-diameter ratio to high standards of size, parallelism, straightness and surface finish has always presented problems. One of the most significant technological advances made to help solve these problems has been the development of the BTA (Boring and Trepanning Association) technique [3]. There are 3 main systems used in deep-hole machining applications. They are the Single Boring Bar System (BTA), Double Wall Boring Bar System (Ejector) and the Gundrilling Systems. These 3 systems all have a common purpose -- to drill holes in a metal workpiece while efficiently removing the cut material/chips. However, the systems differ in ways how they remove the chips from the bore and how they supply the coolant to the cutting edge of the drilling tool [4].

The Gundrilling System (Figure 1-2) -- A pressurized coolant flow is pumped through the interior of the gundrill shank. The coolant exits the drill through holes near the cutting edge. The pressurized coolant then forces the chips through an external flute in the gundrill shank and out of the bore.

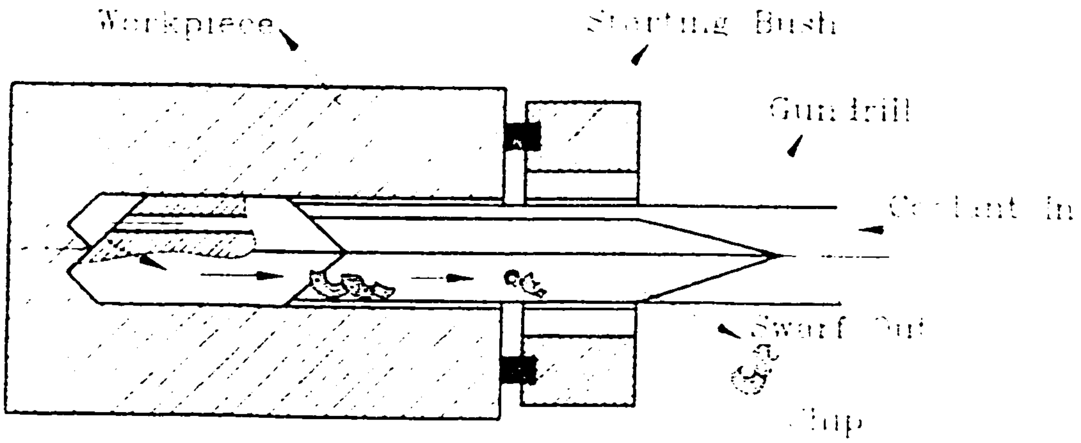


Figure 1-2 Gun-drilling system

The Double Wall Boring Bar System (Ejector Drilling) -- The double tube system involves a boring bar or drill tube which is thread attached to a drilling tool. Inside of this outer drill tube there is an inner tube which creates a void between the O.D. of the inner tube and I.D. of the outer drill tube. Pressurized coolant is then forced through the space where a portion of the coolant is allowed to exit through passages in the inner tube while the most of the coolant is directed to the tools cutting edge. These two coolant streams create a vacuum in the inner tube that facilitates the chip removal through the I.D. of the inner tube (**Figure 1-3**).

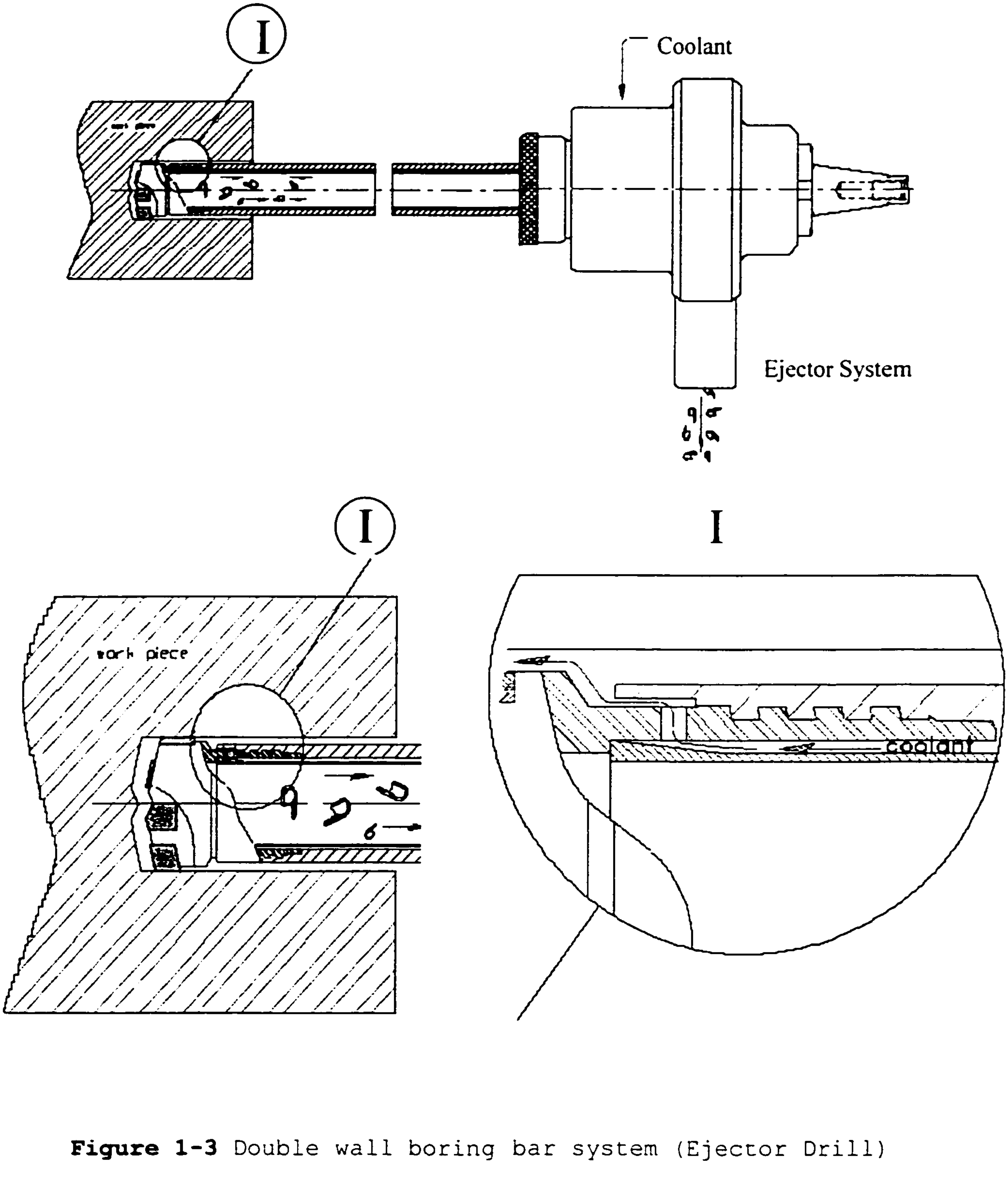


Figure 1-3 Double wall boring bar system (Ejector Drill)

The Single Boring Bar System (BTA) -- The BTA system is a single tube system that has become one of the most successful deep hole drilling systems over the last couple of decades. The single tube system (BTA) is similar to the double tube system in that a boring bar is thread attached to the drilling tool and the coolant and chips are removed from the bore through the I.D. of the boring bar. However, the manner in which coolant is introduced to the cutting edge is different. This system incorporates a fluid transfer unit (Pressure Head) to force coolant to the cutting edge (**Figure 1-4**).

Both the single and the double tube systems offer greater overall reliability than the gundrilling system. The greater reliability is due to an inherent weakness in the gundrill shank design - with respect to external loads such as torque and thrust due to the geometry of the V-shaped flute used to exhaust chips and coolant from the bore. This weakness in the single and double tube systems is eliminated due to much stronger tubular cross section.

The single boring bar system (BTA) is the ideal system for drilling very deep holes because it is rigid and capable of delivering enough pressurized coolant to the cutting edge

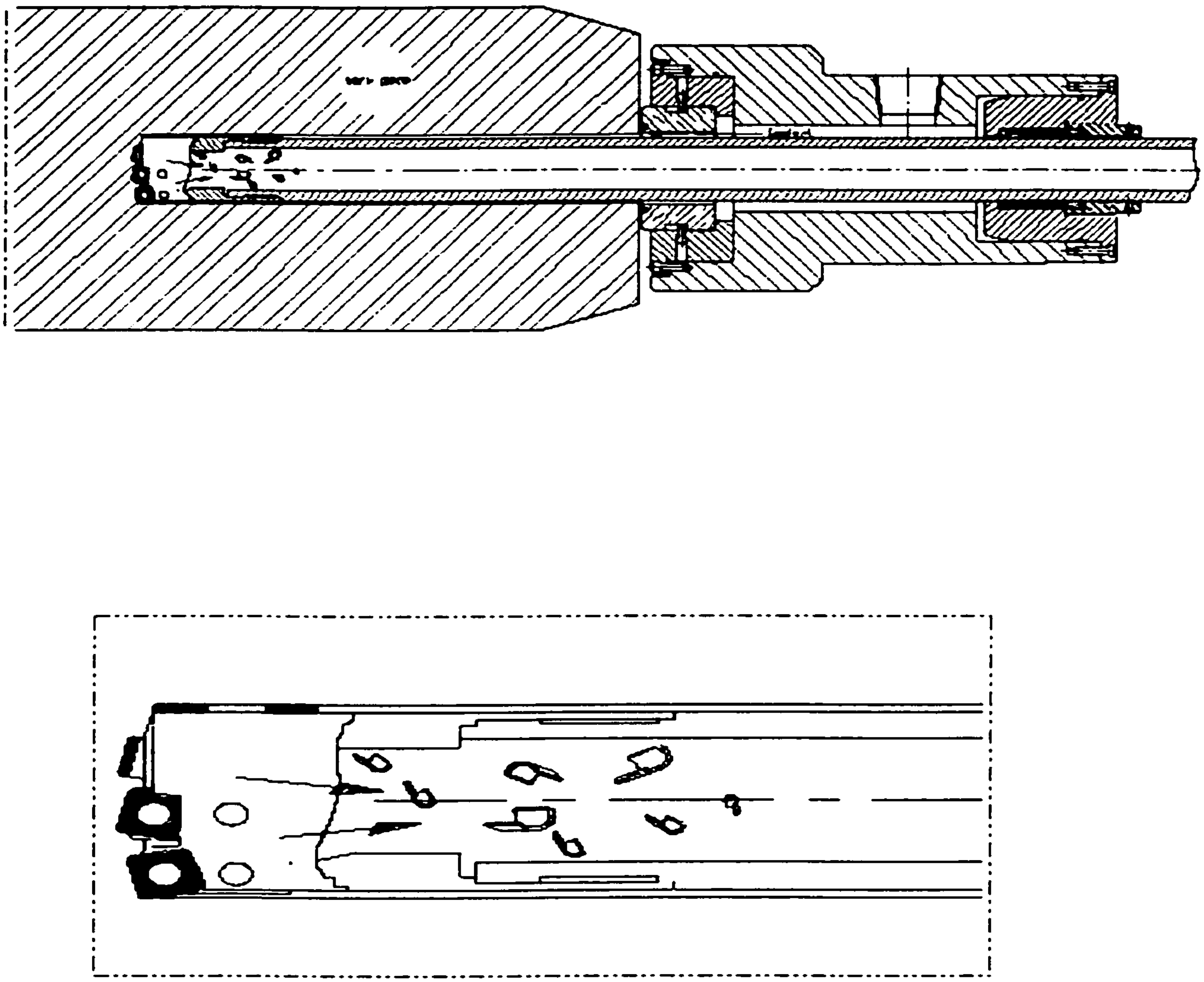


Figure 1-4 Single boring bar system (BTA)

regardless of the bore depth. This is a limitation in the Double Tube System due to the manner in which the coolant is delivered to the cutting edge and the thinner boring bar wall required to accommodate the additional inner tube.

On the other hand the double tube system can be used to convert conventional machine tools such as lathes or milling machines to deep hole drilling machines since it uses a drill tube and inner tube to provide coolant to the cutting edge as well as remove chips with coolant from the bore.

This eliminates the need for a pressure head that is required in the single tube of BTA system.

1.2 Deep Hole Machining Tools

The following are some of the deep hole machining processes that may be carried out using the BTA/STS or DTS systems. Note that the following figures depict BTA/STS deep hole drilling tools.

Solid Drilling/Boring -- Solid boring is used when only one operation is desired to obtain the required bore diameter. Solid Boring tools remove all the material from the bore in a single pass. In addition due to the quality of the bore finish, the most of operations require no follow up machining to 'clean up' the bore (**Figure 1-5**). Multi-edge cutting tools are used to achieve higher material remove rates, and provide performance similar to that of single cutting-edge boring tools in term of tool stability and more accuracy [5].

Trepanning - The less frequently used tools are those known as trepanning tools, which are employed for generating holes by removing material over an annular area and leaving a solid core inside [6]. As with solid boring, trepanning is the single operation necessary to obtain the required hole diameter. Trepanning leaves a core that can be used

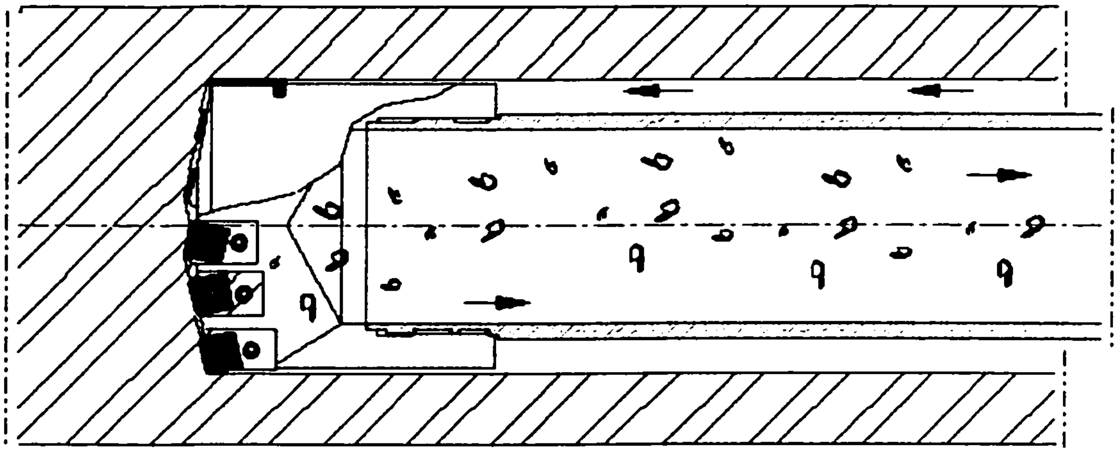


Figure 1-5 Solid drilling/boring with multi-cutting edge

for material analysis or the production of other parts (**Figure 1-6**). This also means that trepanning requires less power than Solid Boring and thus can be used on machines with marginal power.

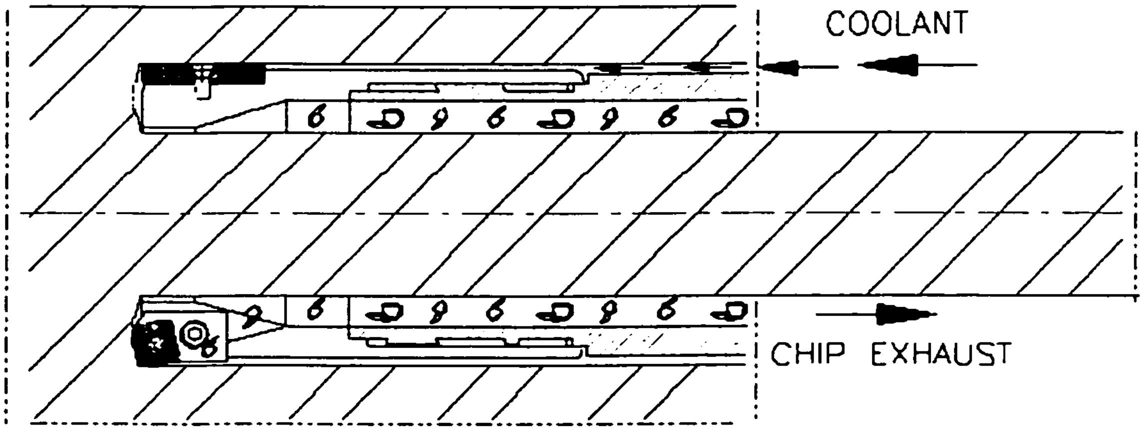


Figure 1-6 Trepanning

Counter boring - Counter-boring or finish boring tools are used with an existing bore. They are used to enlarge an existing bore or to remove any excess stock. Counter-boring tools are often used on low power machines were a small diameter Solid boring tool is used for pre-drilling and then a Counter-boring tool is used to finish the job (**Figure 1-7**). Counter-boring is also used when there is a heat treat process required after the initial hole is drilled or if a stepped holes are required.

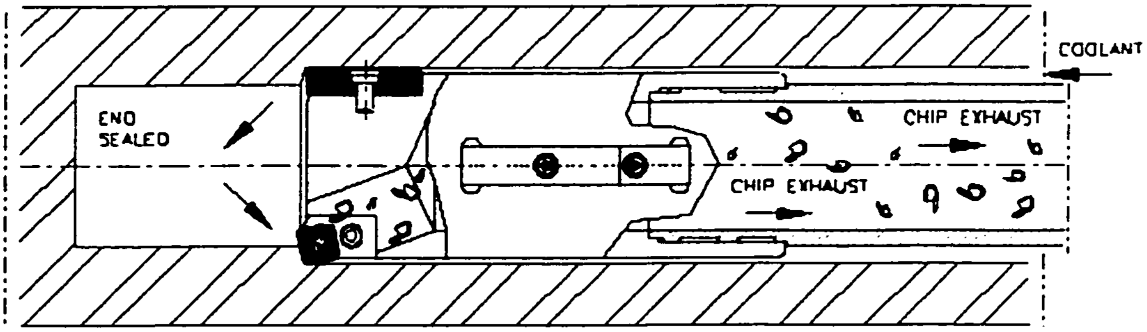


Figure 1-7 Counter-boring

Reaming -- Reamers are similar to Counter-boring tools in that they remove the final material from a pre-drilling (**Figure 1-8**). However, reaming is carried out to obtain a close hole tolerance. Reamers remove less stock than counter boring tools, but they can be operated at much higher feeds and speeds.

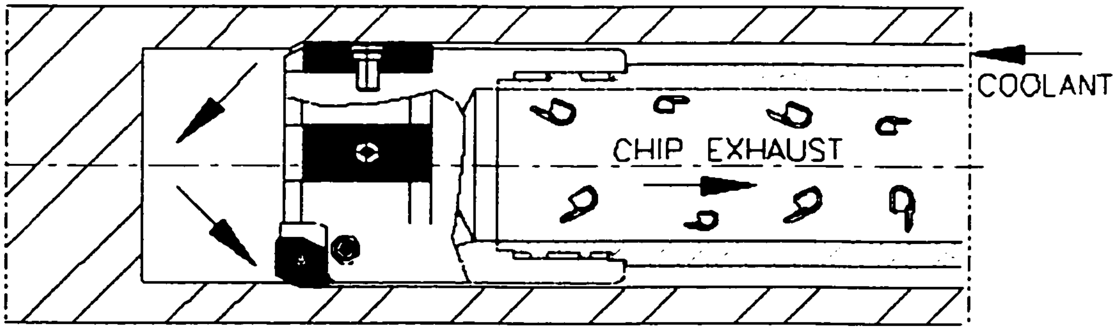


Figure 1-8 Reaming

1.3 Expert Control of Deep-Hole Machining Process

The deep-hole machining process is a highly complex operation in which parameter controls are required at various stages of the process [1]. It is not easy to control these parameters by human operators because many of these parameters are varying during the machining process. The cutting force increases from zero to the maximum when the tool enters into the work piece from the beginning until the entry of the whole guide pads [7]. So the cutting speed and feed must be selected in order to achieve a suitable cutting force. Moreover, the flow rate and the pressure of the cutting fluid also have significant impact on the quality of the hole produced [8][9]. Different flow rates and pressure have to be applied for different operations. The chip shape and its size are other important factors in determining the efficiency of the chip removal [1]. Thus the deep hole machining process is highly labor oriented and needs extensive training and skills of the operator to operate economically. Also, the actual machining operation is internal and not visible to the operator. This requires additional skills to have a feel for the machining condition. The general tendency of the machine operator is to stop the machining process whenever some abnormalities are suspected. This is highly uneconomical as the work piece involved in the process is larger and the tool is expensive. The aim of the operator is to continue the normal machining operation while appropriate modification of the cutting or coolant flow parameters are done. Thus the reliability of the deep hole boring operation entirely depends on the reliability of the operator. This is, however, uneconomical and difficult to provide in the modern industry.

Because of the above mentioned reasons, there is need to control the machining conditions with a minimum human intervention. The expert control system is believed to be a promising solution to the deep-hole machining control problems. The deep-hole machining process involves many uncertain factors. These factors should be monitored and controlled with reasonably reliable technique. Controllers based on mathematical model are not suitable for real-time controlling of the deep-hole machining process because the process involves high degree of uncertainty thus it is not amenable to a reliable mathematical description. Therefore, the problems cannot be solved with conventional programming methods. In spite, it is well documented that the expert system provides a suitable mechanism for handling uncertainty [10]. The deep-hole machine tool is a machine tool for special purposes. It is easy to determine the problems that we want to solve with the expert control system. In addition, one of the most significant technological advancements made has been the development of the BTA technique. The technologies of the Deep-Hole Machining have matured to set up a stage for an expert system. All knowledge required by expert system can be gotten from experienced human experts and can be updated in the application.

Expert systems have a number of attractive features [11]. These are suitable to be used to control the deep-hole machining:

- **Increased availability**. Expertise is available on any suitable computer hardware. In a very real sense, an expert system is the mass production of expertise.
- **Reduced cost**. The cost of providing expertise per user is greatly lowered.
- **Permanence**. The expertise is permanent. Unlike human experts, who may retire, quit, or die, the expert system's knowledge will last indefinitely.

- **Multiple expertises.** The knowledge of multiple experts can be made available to work simultaneously and continuously on a problem at any time of day or night. The level of expertise combined from several experts may exceed that of a single human expert.
- **Increase reliability.** Expert systems increase confidence that the correct decision was made by providing a second opinion to a human expert or break a tie in case of disagreements by multiple human experts. Of course, this method probably won't work if the expert system was programmed by one of the experts. The expert system should always agree with the expert, unless the expert made a mistake. However, this may happen if the human expert was tired or under stress.
- **Explanation.** The expert system can explicitly explain in detail the reasoning that led to a conclusion. A human may be too tired, unwilling, or unable to do this all the time. This increases the confidence that the correct decision is made.
- **Fast response.** Fast or real-time response may be necessary for some applications. Depending on the software and hardware used, an expert system may respond faster and be more available than a human

expert. Some emergency situations may require responses faster than a human may be able and so a real-time expert system is a good choice.

- **Steady, unemotional and complete response at all times.** This may be very important in real-time and emergency situations, when a human expert may not operate at peak efficiency because of stress or fatigue.
- **Intelligent database.** Expert systems can be used to access a database in an intelligent manner

The developments of the computer hardware and software and other control technologies make it possible to develop an expert system control in real time.

1.4 The Structure of the Expert Control System

The expert control system consists of three main parts (**Figure 1-9**). They are Expert System, Control System, and Monitoring System. Expert system is the nucleus of the whole system. The expert system operates all activities of the control system according to the information provided by monitoring system and process requirements.

The control system is an execution part of the system. It is used to control the machining processes in real time according to the information coming from the expert system. For the Deep-Hole Machining the parameters of cutting speed and feed, and fluid flow rate and pressure are controlled by the control system.

The monitoring system is used to keep watching the situations of the machining processes and transfer the information to the expert system in real time. Some of the facts for the expert system come from monitoring system. It is important for expert system to get exact information in real time because all decisions made by the expert system are based on the information. The monitoring system consists of several sensors. These sensors can snap the signals independently.

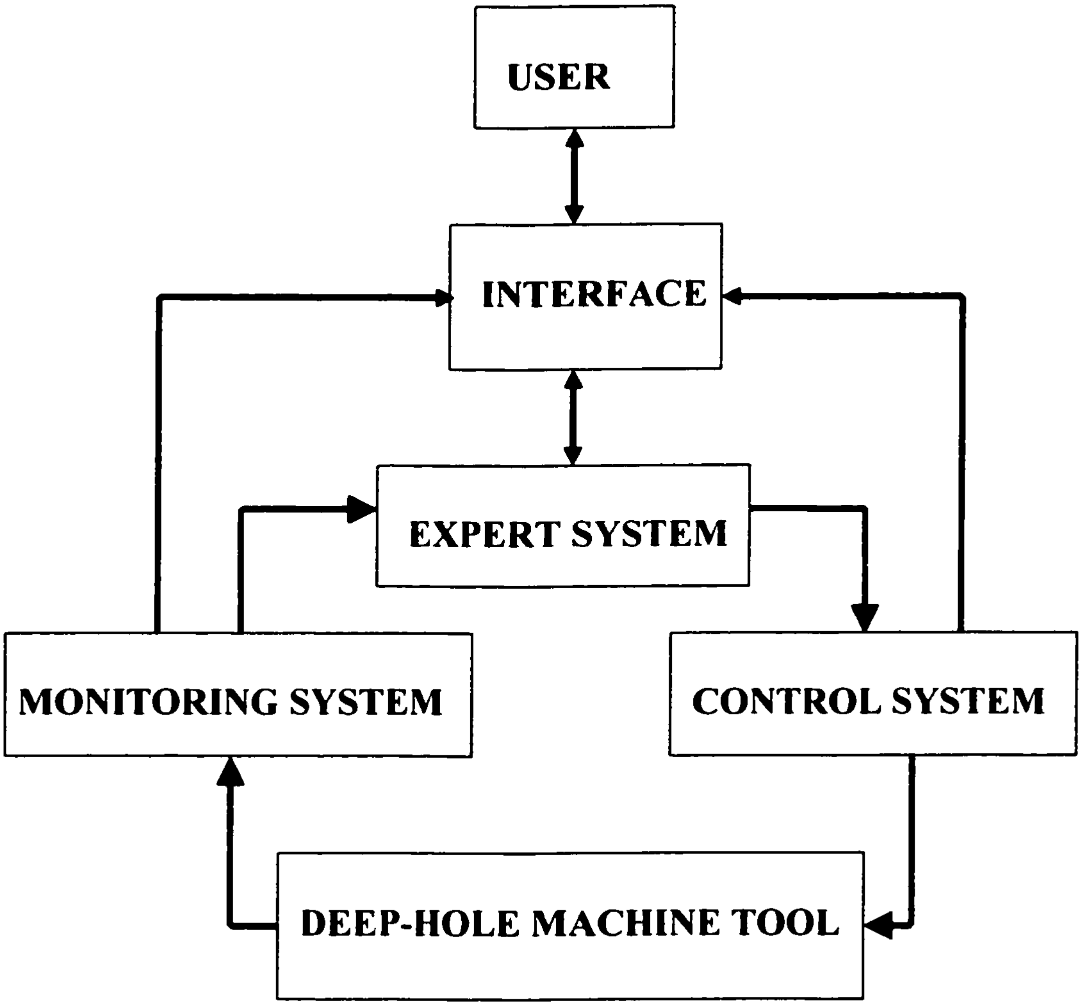


Figure 1-9 Structure of the expert control system

O'Neill and Mullarkey [12] have defined the main objective of the expert control systems for real-time control environment as:

Signal interpretation - in which the objective is to infer the state of the external environment based on the sampled signal(s)

Multi-sensor fusion - in which the objective is to combine information from several different signal sources in order to arrive at a more complete description of the environment than could be determined from any individual sensor.

Anomaly detection - in which the objective is to determine whether the system under study is behaving in an anomalous manner.

Anomaly classification - in which the objective is to determine whether anomalous behavior is due to a problem in the system under study or is due to some artifact of the environment or monitoring process.

Problem diagnosis - in which the objective is to determine the cause of a problem in the system under study.

The development of the expert control system involves many stages. There are three main parts for the whole system and they are closely linked to each other. But the development of each subsystem can be done independently in the different period with different tools and techniques, because the integration technique can be used to make them work together. Certainly the developments need some necessary conditions to unify their function for these subsystems. Therefore, there are a number of general considerations that should be made. The first and foremost is the definition of the goal of expert control system. That is, before we can build an expert control system we must select an appropriate problem domain. The expert control system is not only having similar function with conventional expert system, but also works as a controller in real time.

1.5 Expert System

The expert system is a branch of Artificial Intelligence (AI) that makes extensive use of specialized knowledge to solve problems at the level of a human expert [13]. An expert is a person who has expertise in a certain area. That is, the expert has knowledge or special skills that are not known or available to most people [11]. An expert can solve problems that most people cannot solve or can solve them much more efficiently (but not as inexpensively). Professor Edward Feigenbaum of Stanford University, an early pioneer of expert systems technology, has defined an expert system as "an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solutions" [11]. That is, an expert system is a computer system that emulates the decision-making ability of a human expert. However, the term expert system is often applied today to any system that uses expert system technology. The expert system technology may include special expert system languages, programs, and hardware designed to aid in the development and execution of expert systems. The knowledge in expert systems may be either expertise or knowledge that is generally available from books, magazines, and knowledgeable persons. **Figure 1-10** illustrates the basic concept of a knowledge-based expert system.

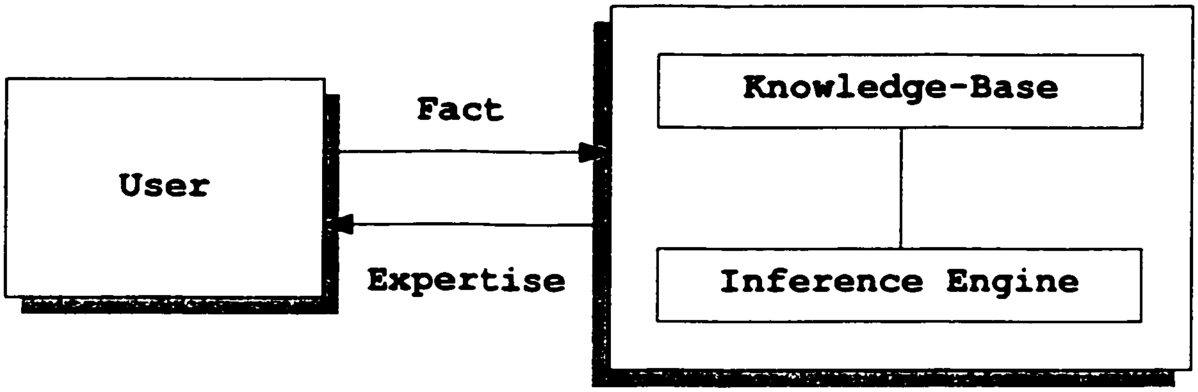


Figure 1-10 Basic concept of an expert system function

The user supplies facts or other information to the expert system and receives expert advice or expertise in response. At the same time, for the Deep-Hole Machining the expert system gets some facts formed by monitoring system and send the commands to the control system as the decisions of expert system. Internally, the expert system consists of two main components. These are the knowledge base and the inference engine. The knowledge base contains the knowledge with which the inference engine draws conclusions. These conclusions are the expert system's responses to the user's queries for expertise.

The elements of a typical expert system are shown in **Figure 1-11**. In a rule-based system the knowledge base contains the domain knowledge needed to solve problems coded in the form of rules. While rules are a popular paradigm for representing knowledge, other types of expert systems may use different representations.

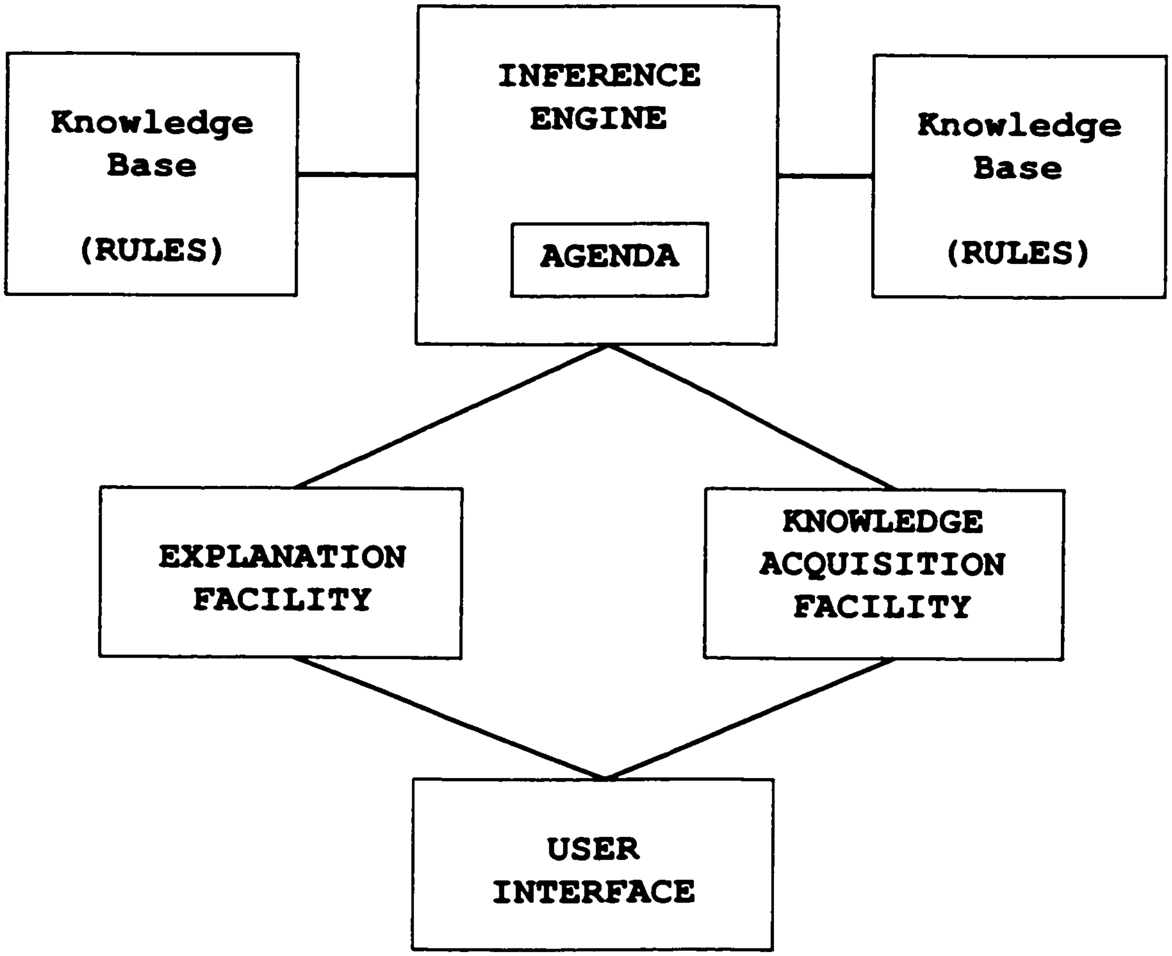


Figure 1-11 Structure of a rule-based expert system

An expert system consists of the following components:

- **User interface** - the mechanism by which the user and the expert system communicate. For the Deep-Hole Machining it is also an interface for the control system and monitoring system to know the working situation of two systems.
- **Explanation facility -** explains the reasoning of the system to a user.
- **Working memory** - a global database of facts used by the rules.
- **Inference engine** - makes inferences by deciding which rules are satisfied by facts or objects, prioritizes the satisfied rules, and executes the rule with the highest priority.
- **Agenda** - a prioritized list of rules created by the inference engine, whose patterns are satisfied by facts or objects in working memory.
- **Knowledge acquisition facility** - an automatic way for the user to enter knowledge in the system instead of having the knowledge engineer explicitly code the knowledge.

Knowledge representation is of major importance in expert systems for two reasons. First expert system shell is designed for a certain type of knowledge representation such as rules or logic. Second, the way in which an expert system represents knowledge affects the development, efficiency, speed, and maintenance of the system.

The purpose of knowledge representation is to organize the required knowledge into a form such that the expert system can readily access it for decision-making purposes. Knowledge does not always come compiled and ready for use. The term knowledge is used to describe a variety of bits of understanding that enable people and machines to perform their intended functions.

The knowledge can be classified into two special types, called a priori and posteriori. A priori knowledge comes before and is independent of knowledge from the sensors. As an example, the statements "everything has a cause" and "all triangles in a plane have 180 degrees" are examples of a priori knowledge. A priori knowledge is considered to be universally true and cannot be denied without contradiction. The opposite of a priori knowledge is knowledge derived from the sensors, or a posteriori knowledge. Because sensory experience may not always be reliable, a posteriori knowledge can be denied on the basis of new knowledge without the necessity of contradictions.

The knowledge base and Inference engine both are computer programs made by knowledge engineer with a special computer language for expert system such as clips, lips, etc [14]. The knowledge engineer first establishes a dialog with the human expert in order to down out the expert's knowledge. This is analogous to a system designer in conventional programming discussing the system requirements with a client for whom the program will be constructed. The knowledge engineer then codes the knowledge explicitly in the knowledge base. The expert then evaluates the expert system and gives a critique to the knowledge engineer. This process iterates until the system's performance is judged by the expert to be satisfactory. The general stages in the development of an expert system are illustrated in **Figure 1-12**.

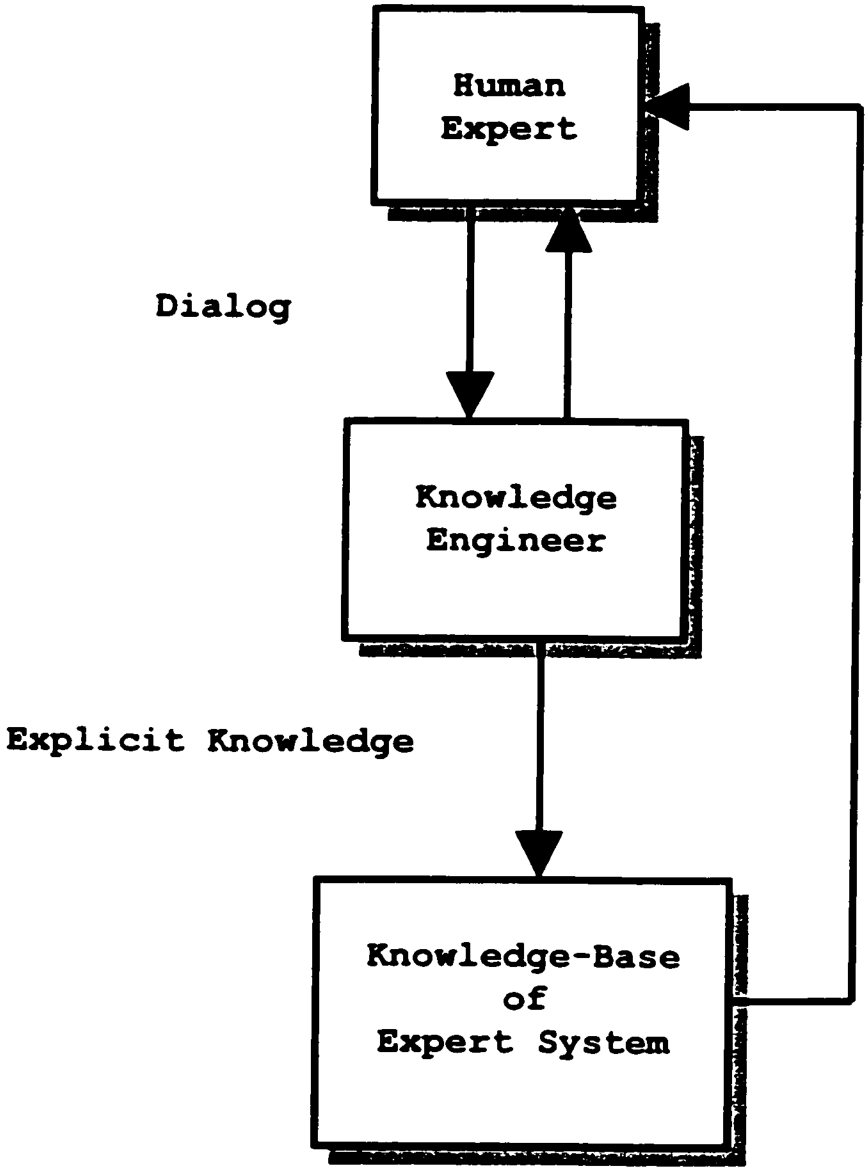


Figure 1-12 Development of an expert system

1.6 Monitoring System

As indicated at the beginning of this chapter, there are two important goals in current research dealing with manufacturing processes [15]. One is to develop integrated, self-adjusting systems that are capable of manufacturing various products with minimal human supervision and assistance. The other is to improve product quality and reduce production cost. To achieve these goals, on-line process monitoring is clearly one of the most important requirements.

As illustrated in **Figure 1-13**, monitoring tasks are mainly composed of three parts: sensing, signal processing and monitoring decision-making. Appropriate sensor signals include force, deflection, acceleration, temperature, pressure, acoustic emission, electric current or voltage, and optical signals. In practice, the major concerns of sensing include cost, reliability, effectiveness, and signal-and-noise ratio.

Signal processing and monitoring decision-making may be considered as an integrated entity and called monitoring methods. A large number of monitoring methods have been

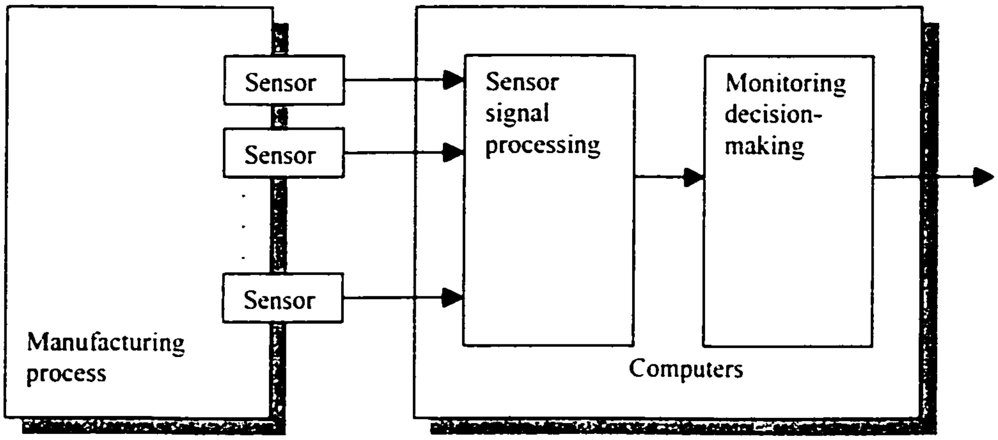


Figure 1-13 Monitoring of manufacturing processes

developed such as expert systems, pattern recognition, fuzzy systems, decision trees, and neural networks. The simplest one is to identify two process conditions (normal and abnormal) using a sensor signal. It can be described by the condition statement below:

$$\textbf{\textit{If }} y < t_x \textbf{\textit{ then normal else abnormal}} \quad (1)$$

where, y is the sensor signal and t_x is a threshold value. If the signal takes distinct values for normal and abnormal conditions regardless of the change of process working conditions and noise disturbances, then this simple statement is the optimal decision policy. However, in most applications, this simple decision-making strategy will not perform satisfactorily. Therefore, more effective monitoring methods are inevitably needed.

1.7 Control system

In control systems employing a human operator as part of the control loop, this information can then be used by the operator to effect a control function manually (e.g., increase the cutting feed rate, reduce the pressure, adjust the cutting fluid flow rate, or change the cutting speed). In automatic control systems the output of the sensing or analyzing device is used to effect a control function without the intervention of a human operator. The former is known as open-loop control systems, the latter as called closed-loop control systems [16]. **Figure 1-14** shows a Simplified description of a control system, and **Figure 1-15** and **Figure 1-16** show the Block diagrams of open-loop control systems and closed-loop control system respectively.

Figure 1.14 Simplified description of a control system

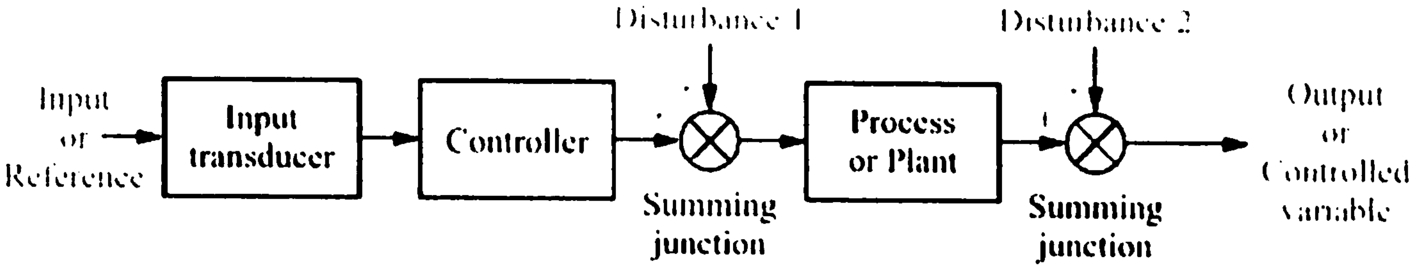


Figure 1-15 Block diagrams of open-loop control systems

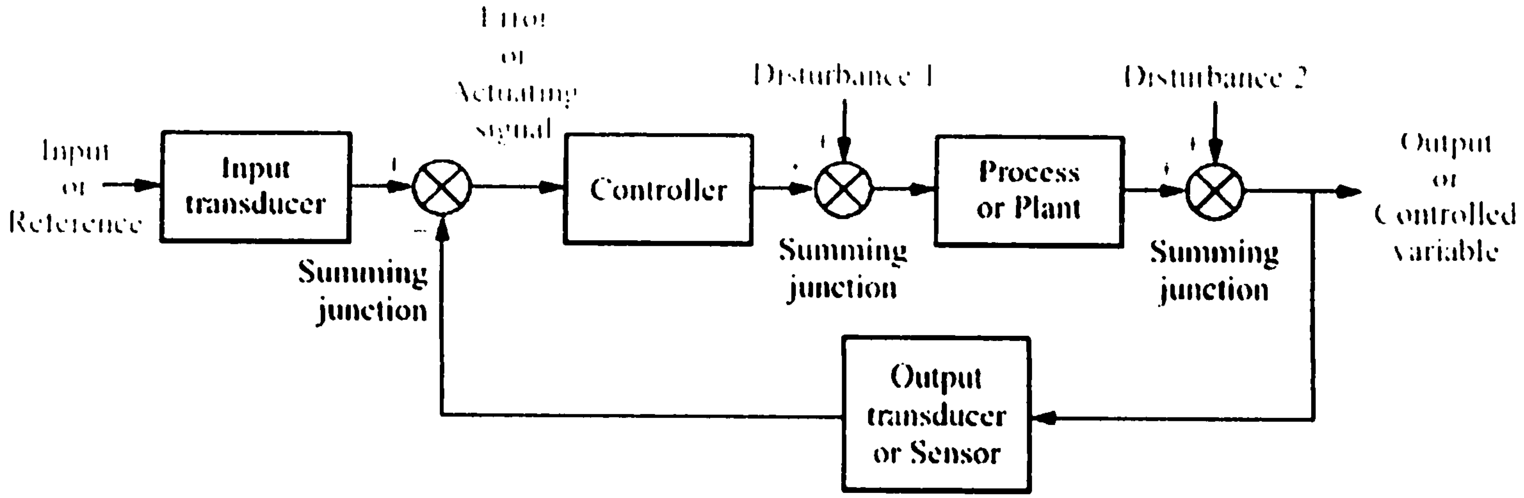


Figure 1-16 Block diagrams of closed-loop control systems

The most commonly used automatic control systems are closed-loop systems employing feedback. A feedback loop includes a forward signal path, a feedback signal path, and a signal summing point, which together form a closed circuit. It operates in the following manner (equivalent terms commonly used in process control are shown in brackets):

A specific quantity within a controlled system (process) is to be maintained at a specified magnitude. This controlled quantity (controlled variable) is measured by a sensing device, usually a transducer (transmitter).

The output of the sensing device, which may or may not have to be conditioned in some manner, is fed to a comparing element, or summing point (set point) in a regulating device (controller). At this point, the signal fed back from the sensing device (feedback signal) is compared with a reference signal (set-point signal). If the two signals are of the same magnitude, or within a relatively narrow tolerance from each other (dead band), no further action is taken. If the two signals differ from each other by an amount larger than that tolerance, a regulating signal is sent to a control device (final controlling element). This signal causes the control device to change a quantity or condition (manipulated quantity or manipulated variable) in the controlled system. The control action remains in effect until the controlled magnitude is at its proper level, as indicated by the feedback signal equaling the set-point signal.

1.8 Scope of the thesis

The principles of the expert control system for deep-hole machining had been already defined by P. S. Subramanya [1]. However, the chip sensor designed and built using a membrane with strain gages mounted on it has been proven as inadequate and incapable of sensing the chip concentration. In addition, there is no effective monitoring system of chip size for deep-hole machining in current industrial applications. Consequently, the scope of this thesis is the development of a real time monitoring device for the chip concentration during deep-hole machining process.

Control of chip size and shape is very important in deep-hole machining for the following reasons:

1) A visual monitoring of chip is obstructed by opaque chip passages.

2) There is no sufficient space available to ensure the chip disposal if chip is too long. Moreover, the excessive chip length may cause the restricted chip passages clogged and the operation completely stopped.

3) As long chips could clog the passages in the tool that will cause the operation to cease, too short chips, however, may get stuck in the gaps between the relatively moving parts and eventually damage the machined surface and/or the tool guiding pads. In addition more force on the tool is generated and more energy is expensed during the operation. This means that the chip size should be maintained within certain limits determined by experience.

The above mentioned reasons strongly indicate an importance of having a reliable chip size monitoring system providing a signal strong enough that it can be used for an automatic control of the machine tool.

1.9 Thesis Outline

Chapter 2 describes the principles of sensing of the chip size. A sensor which has been selected is a proximity inductive sensor commercially available from suppliers. This chapter also deals with the design of a layout of the sensing system housed into a nonmetallic elbow designed and built to secure the sensing practically all chips passing by. The nonmetallic environment is a must for this sensor since it doesn't work in a metal surrounding.

In Chapter 3, monitoring methods of manufacturing processes are reviewed. The method for chip size monitoring in deep-hole machining process is discussed and selected according to these principles. The data acquisition method is selected and the experimental setup is assembled. The monitoring indexes and process conditions, acquired from the data, are defined with view of utilizing them for expert control of the process.

In chapter 4, the experiments were described and results recorded, the experimental data was processed and analyzed. The system introduced in chapter 2 and the method selected in chapter 3 proved to be very reliable. The signal clearly and reliably maps the relationship between monitoring indexes and process conditions.

The chapter 5 contains the conclusions and states the principal contribution of the thesis as well as the recommendations for future work.

Chapter 2

Chip Size Monitoring System

2.1 Introduction

Chip blockage is a long time bottleneck in the deep-hole machining [18]. Therefore, chip shape and its size control is very important in this machining process. The basic functional elements of the chip control are efficient breaking and efficient removal of chips [19]. In general, in processes such as turning, milling, and shaping for which a bigger chip discharge space is available the chip breaker is often enough to ensure the chip discharging. But for processes such as drilling, deep hole drilling where no sufficient space is available, several techniques have been used for the chip breaking. Such as different cutting tool design and geometries are subject to vibration, and pressurized cutting fluid effects. The pressurized cutting fluid is mainly used for efficient removal of chips. A satisfactory chip discharge is the prerequisite of a successful deep-hole machining. For the given cutting tool and workpiece material the feed rate has most effect on the chip size where smallersize of chips has higher frequency of chip count [20].

A monitoring system of chip size is undertaken since a blockage of its passages from the cutting zone can occur. Hence it is necessary to ensure the chips broken into small size. It has been found that an adaptive control of BTA drilling was only possible if the removal of chips was guaranteed [18], hence extensive efforts were conducted to monitor the chip size using (1) the thrust force and the torque exserted on the tool, (2) the noise during the drilling process, (3) the frequencies of chips impinging on an accelerometer, (4) the frequencies of chips impinging on proximity sensor, (5) ultrasonic sensor. More functional and simpler sensing system can be used because of the development of sensor technologies and materials. Experimental results showed that the approach with proximity sensor had a better potential [20].

For the purpose of developing a chip size monitoring system a special NC deep-hole drilling machine tool with a highpressure cutting fluid flow station was used in the deep-hole machining lab. **Figure 2-1** shows the deep-hole machining system with chip state monitoring system.

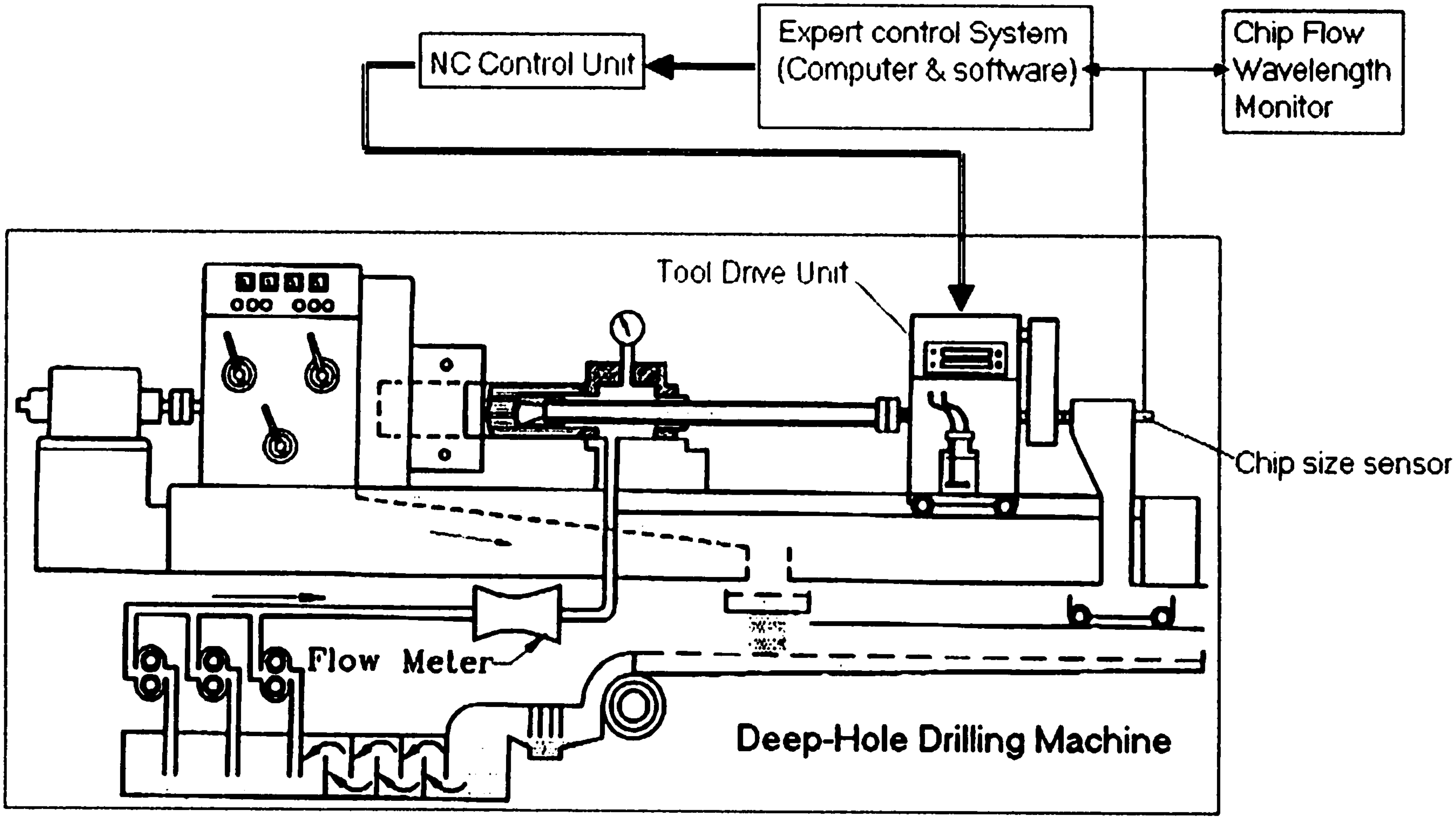


Figure 2-1 Deep-hole machining system with chip state monitoring system

2.2 Sensors for the Chip Statues Monitoring

A sensor is simply a device that provides a usable output in response to a specific measurement: the physical quantity, property, or condition that to be measured [15] . Sensors have contributed significantly to recent advances in manufacturing technology. Using a sensor makes a process or system more automated and removes the need for human operators to monitor and control the situation.

As it was mentioned before, there are several methods which have been used in chip statues monitoring with different sensor systems for deep-hole machining. In the particular metal cutting process of the deep-hole machining, the characteristics of the chip size would be detected in a best way by applying Inductive Proximity Sensor [20]. **Figure 2-2** shows the Inductive Proximity Sensor that was implemented for the experiment.

The reason the inductive proximity sensor has been selected is that it can be specially used to detect metal objects, when there is no physical contact between the object and the sensor. It is the type of sensor that uses an electromagnetic field to detect when metal object is near. This type of sensor is generally used to sense at distances less than one inch [21]. It does this by generating an electromagnetic field. With the ability to detect at close range, inductive proximity sensors are very useful for precision measurement and inspection applications.

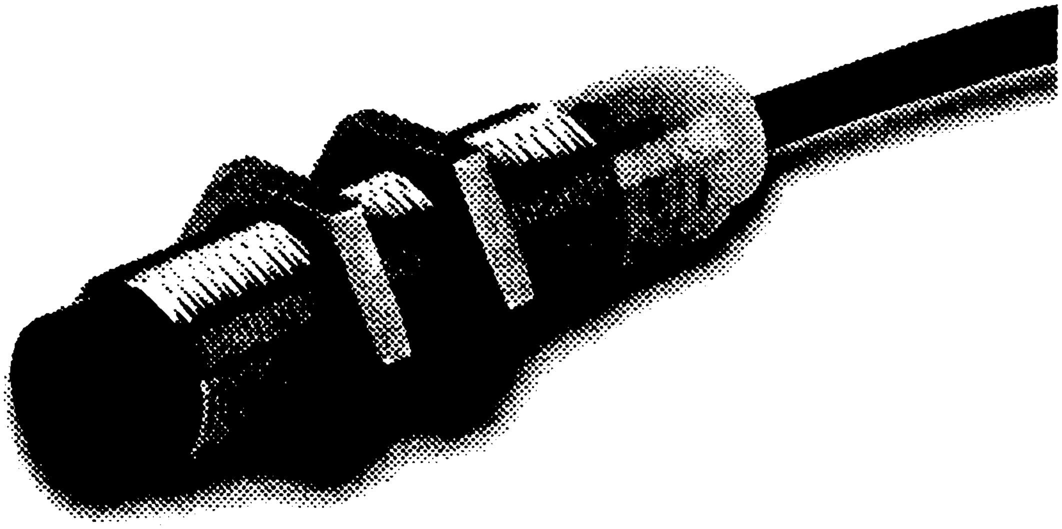


Figure 2-2 Inductive Proximity Sensor with Extended Range

Strengths of the inductive proximity sensor:

- Immune to adverse environmental conditions;
- High switching rate for rapid response applications;
- Can detect metallic targets through non-metallic barriers;
- Long operational life with virtually unlimited operating cycles;
- Solid-state to provide a "bounce free" input signal to PLCs(Programmable Logical Conrol) and other solid-state logic devices.

Weaknesses of the inductive proximity sensor:

- Limited *sensing range(4"* or 100 = maximum);
- Detects only metal objects;
- May be affected by metal chips accumulating on the sensor face.

Inductive proximity sensors produce an oscillating and invisible radio frequency (PF) field at the gensor face. When metal objects are brought into this field, this oscillating field is affected. Each type and size of sensor has a specific sensing range switch point so that metal target detection is very accurate and repeatable.

The presence of a metallic target interrupts the field and alters (by damping) the current in the sensor coil (eddy *current* kill) causing the detector circuit to sense the change. The sensor then triggers an output to a connected device.

Figure 2-3 shows the sensor components and the work process step-by-step:
A metal object, or target, enters the sensing field.

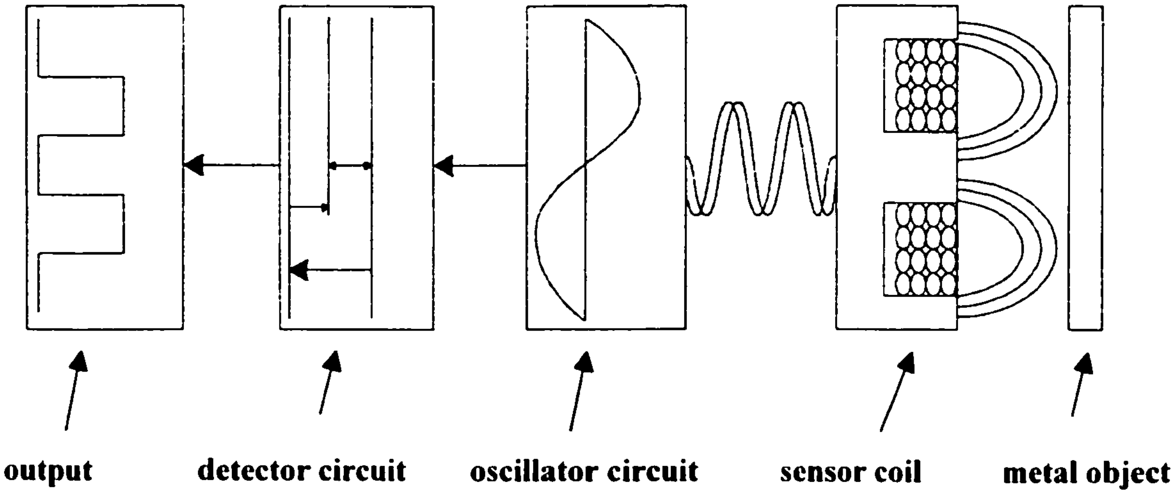


Figure 2-3 Sensor components and the work process

The **sensor coil** is a coil of wire typically wound around a ferrite core. If one could see the electromagnetic field created by it, it would be a cone shape. The target will pass through this field. The ferrite core shapes the field and the size of the coil determines the sensing range.

The **oscillator circuit** causes the field to cycle at a specific set radio frequency (100 KHz to 1 MHz) . The presence of metal causes a change in the oscillation, and an eddy current forms on the target. The metallic object induces a change in the magnetic field. This change creates a damping effect on the amount of signal that cycles back to the sensor coil.

The **detector circuit** senses the change and switches ON at a particular set point (amplitude). This ON signal generates a signal to the solid-state output.

The **output circuit** remains active until the target leaves the sensing field. The oscillator responds with an increase in I amplitude, and when it reaches the set point, the detector circuit switches OFF. The output returns to its normal state.

According to the requirement of the chip status monitoring in the deep-hole machining and the property of the inductive proximity sensor, the sensor (ES7-30LE22-CD) from Cutler-Hammer was selected for the experiment. The specifications of the sensor have been listed in the **Table 2-1**.

Table 2-1 Specification of **E57-30LE22-CD** Inductive Proximity Sensor

Diameter	30 mm
Sensing Range	22 mm (Extended Range)
Shielding	Semi-shielded (NPN)
Connection Type	3 - pin Micro DC Connector
Output	N.O. (NPN)
Operating Voltage	10 - 50V DC
Maximum Load Current	200 mA
Switching Frequency	300 Hz
Leakage Current	600 μA maximum
Voltage Drop	1.0 V maximum
Repeat Accuracy	< 3%
Output Indicator LED	Light when output is ON
Operating Temperature	- 25 to 70 C degree
Enclosure Ratings	NEMA 4, 4X, 6, 6P, 12 and 13 (IP67)
Shock	30g sine wave, 11 mS per IEC68-2-76
Vibration	10 to 55 Hz, 2 inch amplitude in all there planes
Housing Material	303 stainless steel
	PVC high flex, oil/water resistant, 22 AWG

2.3 Data Acquisition System

In general the data acquisition system (DAS) is the analog interface to the digital world [22]. A graphic representation of where the data acquisition system "fits in" is found in **Figure 2-4**.

Once the parameter to be measured is translated into the analog-electrical domain, the DAS performs the translation to the digital-electrical domain. In some cases the DAS simply records, or stores, the digital data, while more sophisticated systems may be capable of analysis or further processing. For instance, a DAS may be as simple as a digital voltmeter (DVM), which displays its output as a decimal readout, or it may be complex enough to contain a large-scale computer as part of its hardware.

Today, most researchers are using personal computers with PCI, PXI/Compact PCT, PCMCTA, USB, IEEE1394, ISA, or parallel or serial ports for data acquisition in laboratory research, test and measurement, and industrial automation [24]. Many applications use plug-in boards to acquire data and transfer it directly to computer memory. Others use DAQ hardware remote from the PC that is coupled via parallel or serial port. Obtaining proper results from a PC-based DAQ system depends on each of the following system elements.

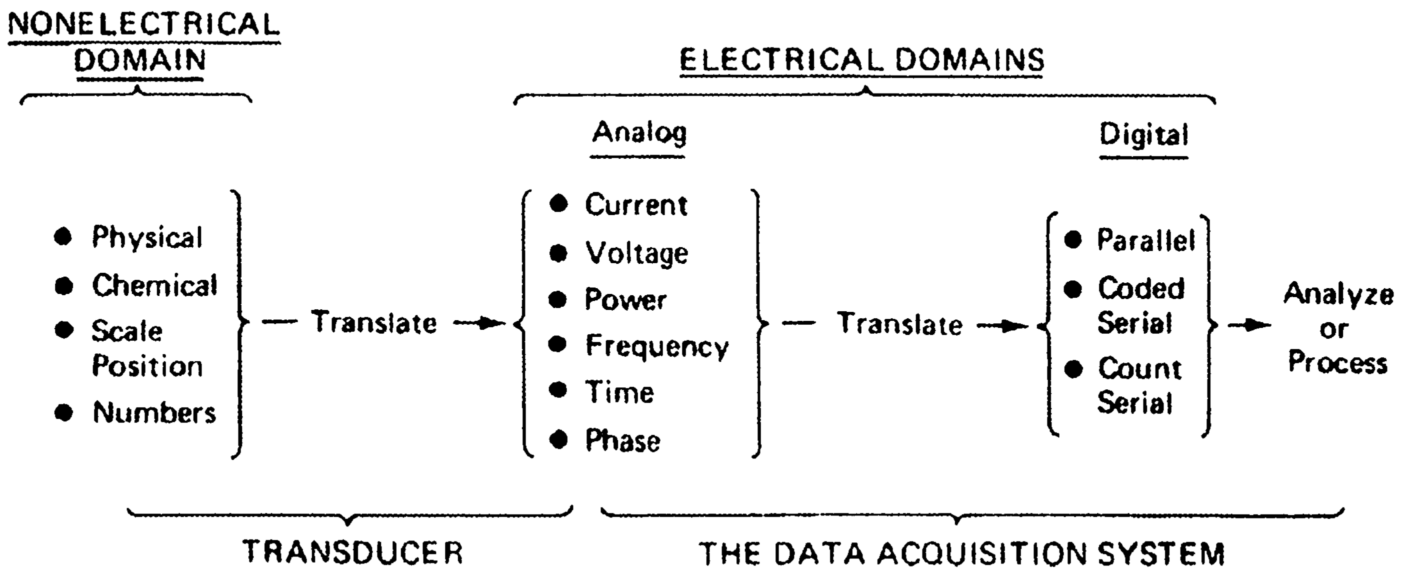


Figure 2-4 Data acquisition system fits

- The personal computer
- Transducers (Sensors)
- Signal conditioning
- DAQ hardware
- Software

The **computer** used for the data acquisition system can drastically affect the maximum speeds at which it is able to continuously acquire data. Today's technology boasts Pentium and PowerPC class processors coupled with the higher performance PCI bus architecture as well as the traditional ISA bus and USB. With the advent of PCMCTA, portable data acquisition is rapidly becoming a more flexible alternative to desktop PC based data acquisition systems. **Transducers** sense physical phenomena and provide electrical signals that the DAQ system can measure. In each case, the electrical signals produced are proportional to the physical parameters they are monitoring. The electrical signals generated by the transducers must be optimized for the input range of the DAQ board. **Signal conditioning** accessories can amplify low-level signals, and then isolate and filter them for more accurate measurements. In addition, some transducers require voltage or current excitation to generate a voltage output. Today's **DAQ Hardware** is made on a DAQ board. In general there are analog input, analog output, triggers, Real-Time System

Integration (RTSI) Digital I/O, and Timing 1/0 with the DAQ board.

A basic data acquisition system has been shown in the block diagram in **Figure 2-5**. Each of the blocks in this figure represents a particular data acquisition function.

The DAQ board shown in **Figure 2-5** is not necessary for the chip size monitoring with the inductive proximity sensor from Culter-Hammer, since the inductive sensor used for chip status monitoring can output digital signal itself. The signals from sensor are direct input to the computer through the parallel port, and save the data with the designed software. Wavelength Monitor was used to show the signals from the sensor. **Figure 2-11** shows the Wiring Diagram of the chip size monitoring system.

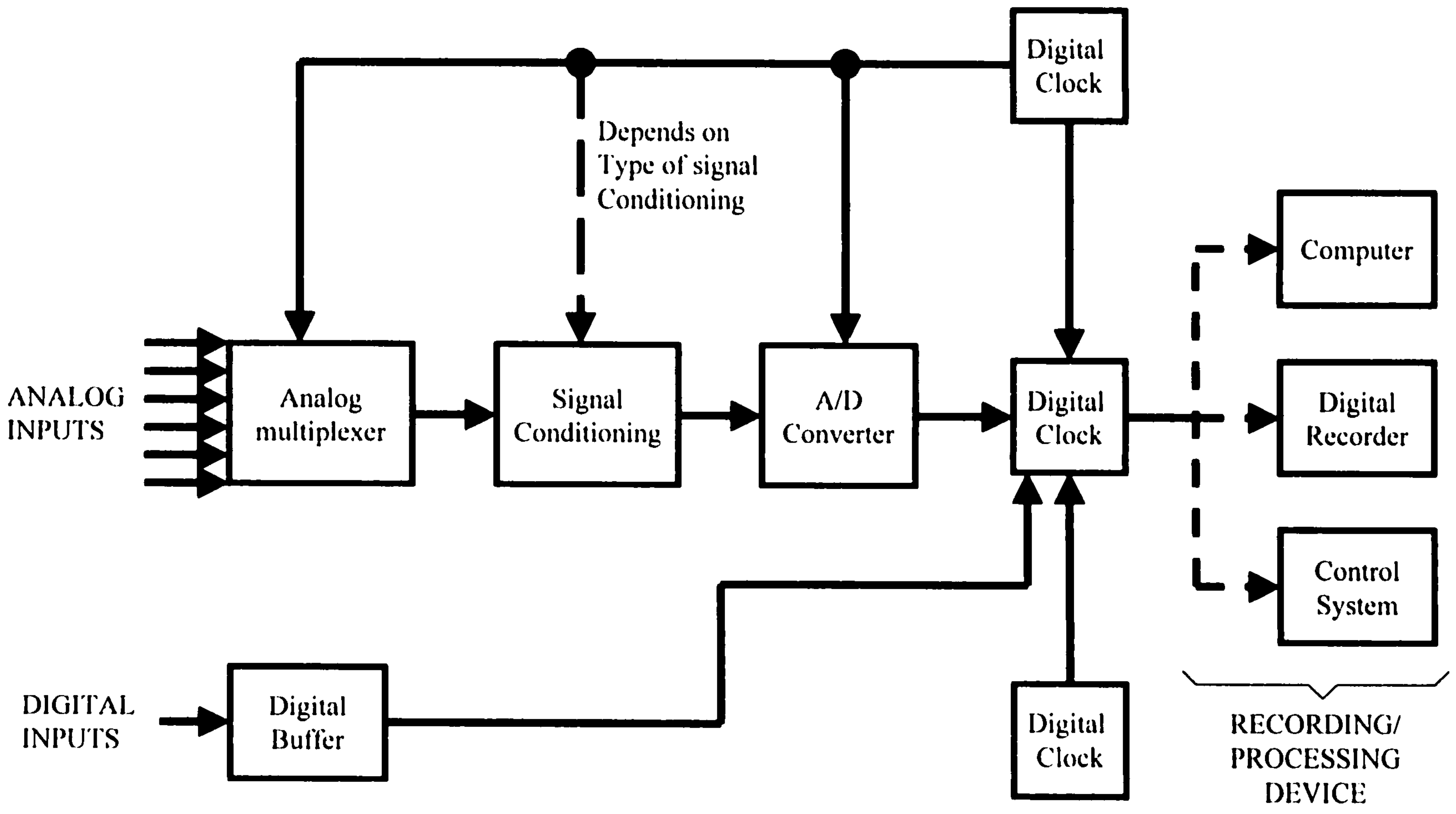


Figure 2-5 Basic data acquisition system block diagram

2.4 Mechanical Design

Based on the deep-hole machining system we have in the lab, the mechanical system has been designed and biult to hold the sensor for the chip size monitoring. **Figure 2-6** and **Figure 2-7** show the details of the mechanical layout. The drawings of each component have been attached in the **Appendix 1**.

The position of the sensor is illustrated in **Figure 2-6**. It is the best position for the chip size monitoring with the inductive proximity sensor because it is the position the most of chips pass through on the way to the chip trap. Part 2 is used to create nozzle of chips jetting from the boring bar to the appropriate position in the discharge channel. The sensor front surface is placed at 45 degree with respect to the centre line of the boring bar downstream of the nozzle. The nozzle at the position can sence most of the discharged chips to the valid sensing signal, providing enough space at the front of the nozzle for chips discharge. **Table 2-1** shows that the valid sensing distance of the sensor is 22 mm from the front of the sensor. From **Figure 2-7** it can be seen that the most space at the front of the nozzle is also in the valid sensing area.

Since the inductive proximity sensor is very sensitive to metal, the metal material couldn't be used for the discharging passage and nozzle in front of the sensor and the elbow used to hold the sensor in the valid sensing area. Instead, the … is used for these components.

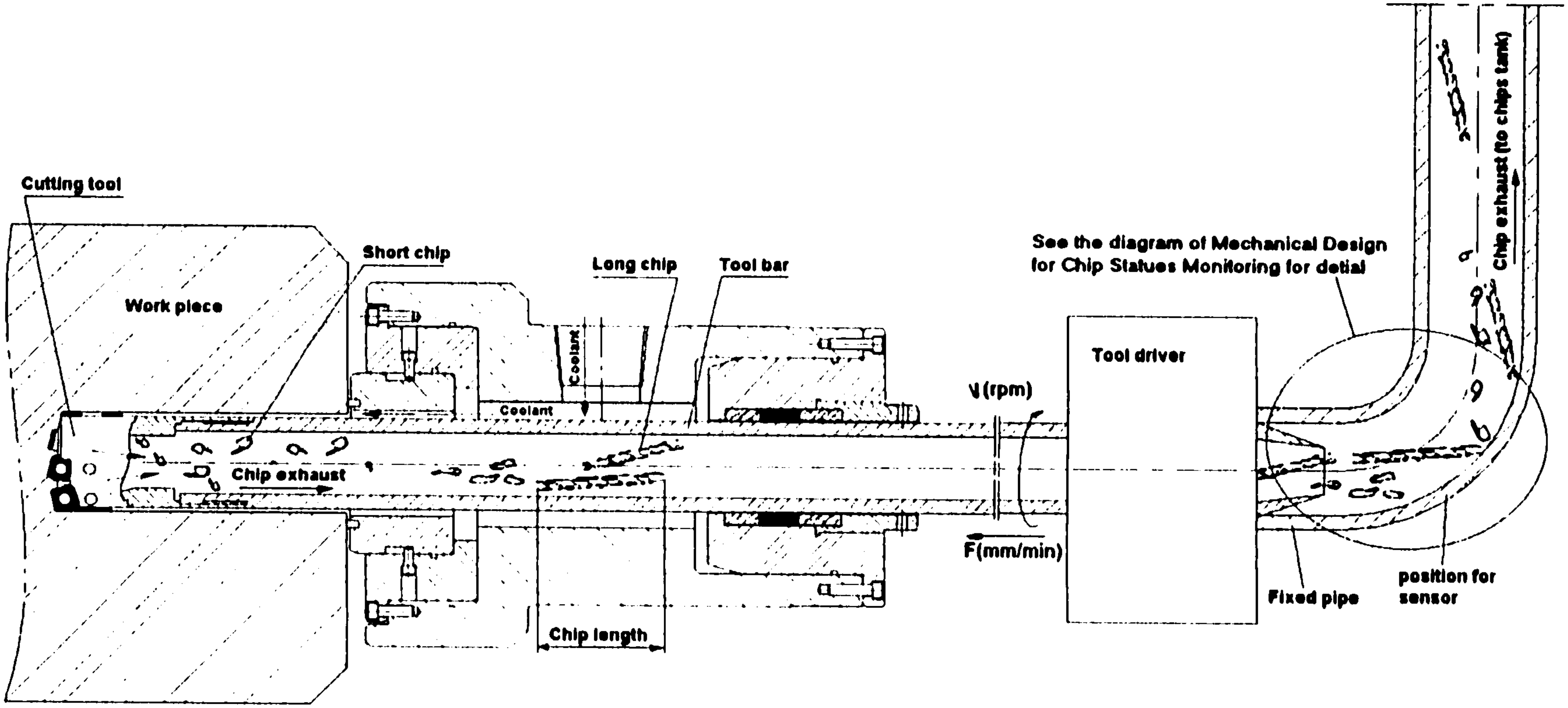


Figure 2-6 Deep-hole machining and chip status monitoring

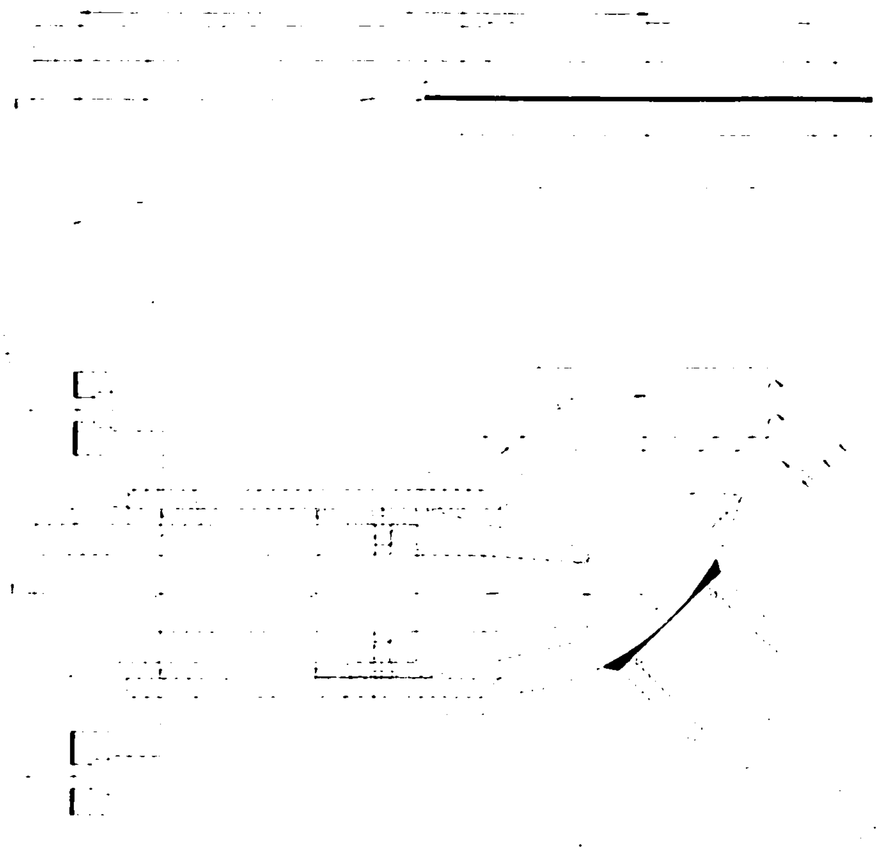


Figure 2-7 Mechanical design of Sensor holder mount

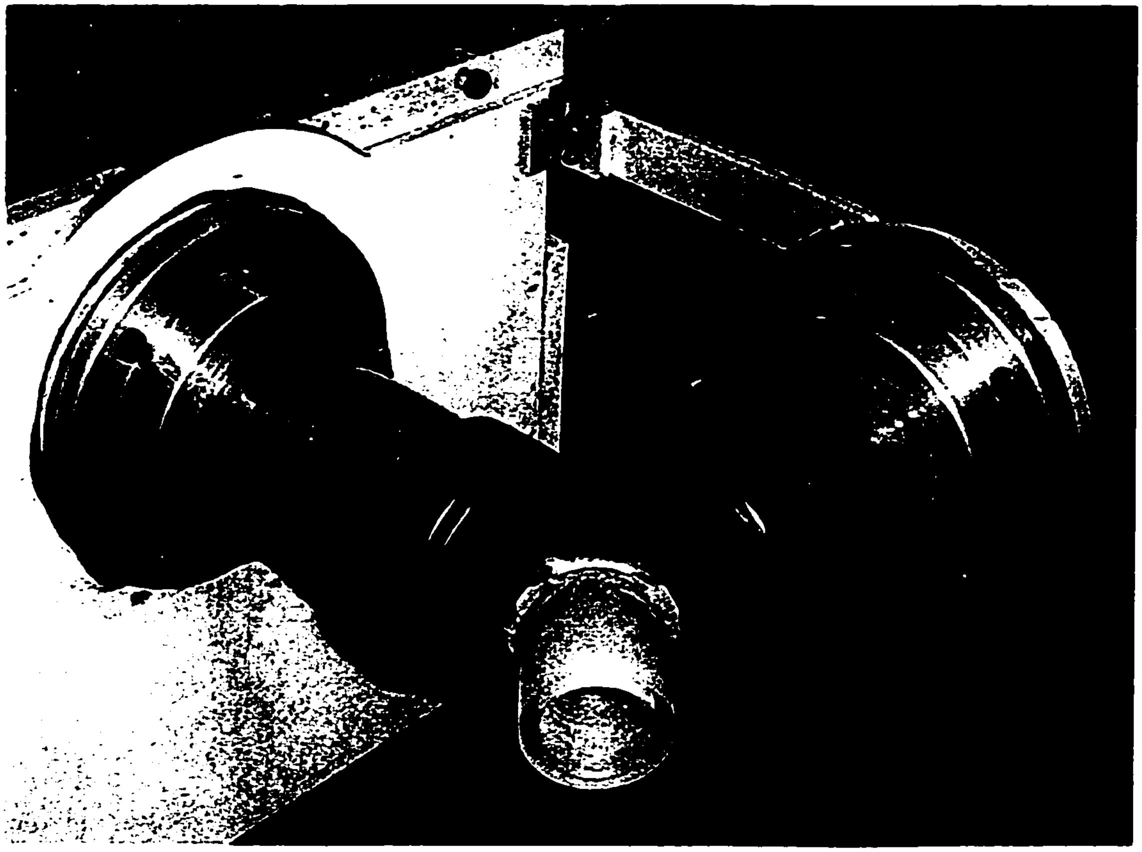


Figure 2-8 Sensor holder mount

2.5 Interface Design of Sensor and Computer

An interface is a system consisting of hardware, software, or both that allows two dissimilar components to interact [25]. For automated data acquisition, suitable sensors and associated hardware are needed to connect the sensor(s) to a host computer. The software is also needed to transport and translate the data from the sensor(s) to the computer.

2.5.1 Hardware

Conventional methods for connecting external hardware to a PC include the use of plug-in interface cards, such as a DAQ card discussed above in this chapter. In the experiment of chip size monitoring a very simple electrical circuit was designed so that it can connect sensor to the PC through the parallel port directly.

The sensor interfaces to computer through the output circuit. For the Inductive Proximity Sensor the control voltage type is a determining factor when considering output type. Control voltage types, whether- AC, DC or AC/DC, can be categorized as either load-powered or linepowered. The sensor used in the experiment uses the line-powered voltage **(Figure 2-9)**. Line-powered switches derive their power from the line and not through the load [22]. They have three connection points to the circuit, and are often referred to as 3-wire switches. The operating current the switch pulls from the line is called the burden current. This is typically 20 mA. Since the operating current doesn't pass through the load, it is not a major concern for circuit design.

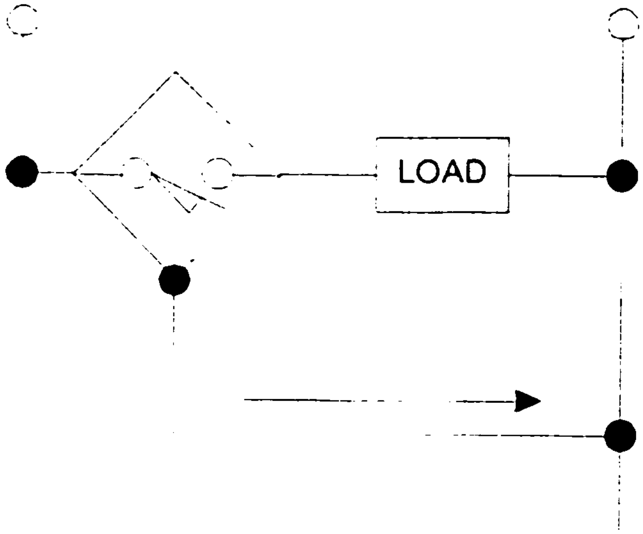


Figure 2-9 Line-powered/3-wire circuit

There are three output types available for the Inductive Proximity Sensor - Relay, Triac and Transistor. The sensor used in the experiment has the transistor output **(Figure 2-10)**. A transistor is a solid-state device designed to control DC current. It is most commonly used in low voltage DC powered sensors as the output switch. The output transistor is connected to the negative DC. Current flows from the positive terminal through the load, to the sensor, and to the negative terminal. The sensor "sinks" the current from the load.

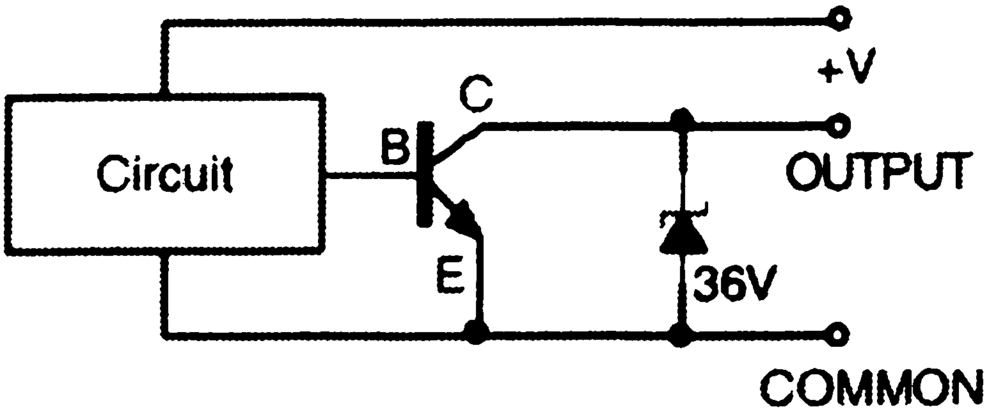


Figure 2-10 NPN transistor output circuit (sinking)

Figure 2-11 shows the wiring diagram of the chip size monitoring system.

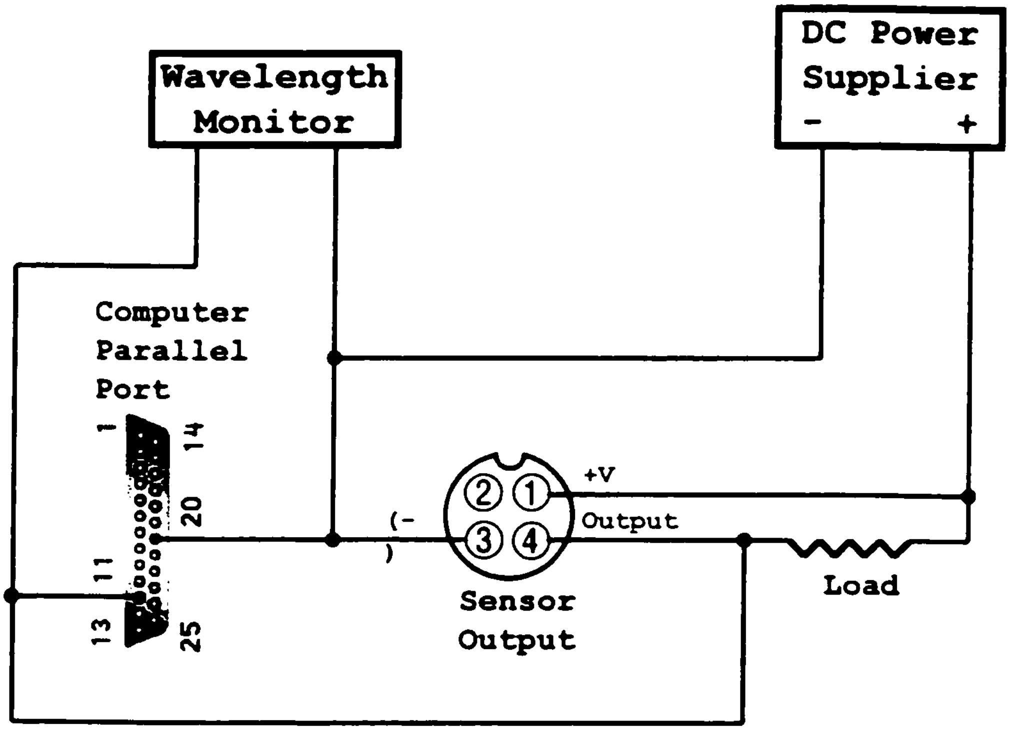


Figure 2-11 Wiring diagram of the chip size monitoring system

2.5.2 Software

A program in C language has been designed for data acquisition from the sensor. The program controls the computer to read the data when it gets the "ready" signal from pin 11 that is connected to the sensor. The program interrupts the reading for 50 ms a second after each reading. That is, if the sensor is busy, it will charge Pin 11. Then, it will drop the voltage below 0.5 volts to let the computer know it is ready to receive data. The computer begins to read the frequency of the chips flow from Pin 11. Reading is interrupted for 50 ms a second after, and then the frequency is read again.

The program in C language is attached as **Appendix 2**.

2.6 Monitoring system Offline test

In order to make sure the monitoring system works correctly, a simulation system was built to do the offline test **(Figure 2-12)**. Instead of the chips flow, a motor drove a metal piece repeatedly coming to the valid sensing area at front of the sensor with a stable frequency. The sensor caught the metal piece every time it passed and the frequencies of occurance recorded by the computer were same as motor speed.

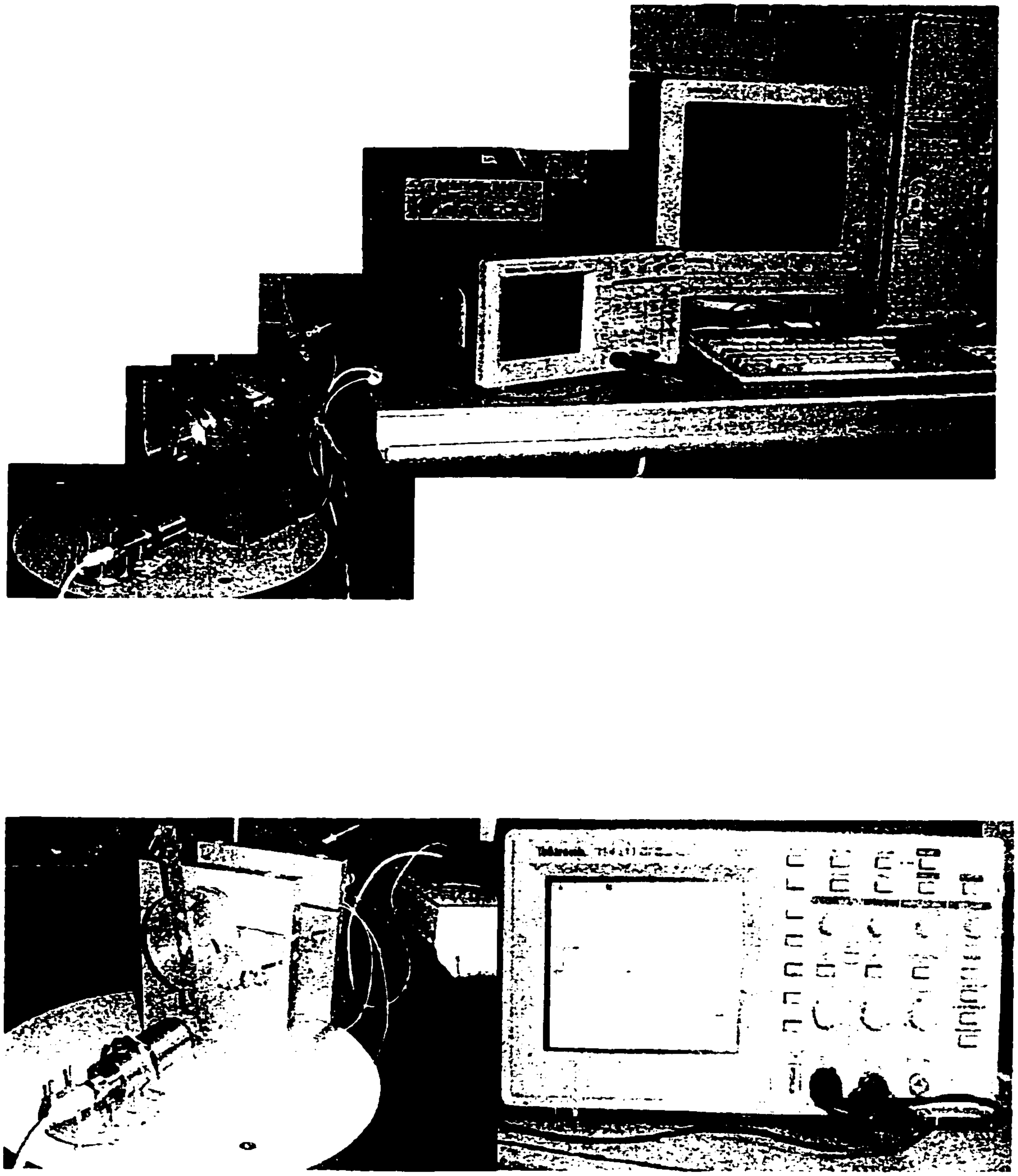


Figure 2-12 Monitoring system offline test

2.7 Experimental Setup

The schematic experiment setup is shown in **Figure 2-1**. The inductive proximity sensor, Cutler-Hammer **E57-30LE22-CD**, was fixed at the bend of the discharge channel for monitoring of the chip size **(Figure 2-8)**. The sensor was connected with the computer (read data) and a wavelength meter (monitor the signal graphics) via the very simple electrical circuit **(Figure 2-11)**.

Two groups of experiment were done to get the initial data of frequencies of chips flow. The difference between two groups is cutting speed. One is 99 m/min, and another one is 88 m/min.

The parameters used in the experiment include:

Work piece material: C-1045;

Tool: BTA - American Heiler d = 35 mm;

Volume of coolant flow: Q = 52 gallons/min = 198 I/min;

Pressure of coolant flow: p = 280 psi;

Cutting speed: v = 99 m/min, 88 m/min;

Feed rate: from 21 mm/min(0.023 mm/rev) to 53 =/min(0.066 mm/rev).

A total of 32 cutting experiments have been conducted with different cutting feed rate because the feed rate has the most effect on chip size where smaller chip size is abtained at higher frequency of occurance [21].

Chapter 3

Monitoring Method

3.1 Introduction

In general, monitoring is composed of two phases: learning and classification. In the learning phase, the key issue is to establish the relationship between monitoring indices (selected signature features) and the process conditions. Based on this relationship and the current sensor signals, the process condition is then estimated in the classification phase. The monitoring methods include pattern recognition, fuzzy systems, decision trees, expert systems and neural networks.

The monitoring methods can also be divided into two categories: model-based methods and feature-based methods [15].

3.1.1. Model-based monitoring methods

Model-based monitoring methods can be used for many manufacturing processes. For these processes, sensor signals can be considered as the outputs of a dynamic system in the form of time series. Consequently, process monitoring can be conducted based on system modeling and model evaluation. According to the definition in Willems [25], a dynamic system can be represented by a triple {*T*, **W**, **B**}, where *T* represents the set of time instances that are relevant to the system. **W** is the signal alphabet representing the space in which the variables of interest take on their values, and through which the system interacts with its environment. The behavior **B** consists of those trajectories **w**: *T* → **W**. Dynamic systems may be nonlinear and time-variant. However, linear time-invariant systems are much better understood. A linear time-invariant system can be described by a number of models such as state space model, input-output transfer function model, Auto-Regressive (AR) model, and Autoregressive and Moving Average (ARMA) model. Also, there are two types of methods for model parameter estimation: exact modeling methods and approximate modeling methods. These methods are systematically studied in Willems [25]. Among various models, the Dynamic Data Systems (DDS) methodology is particularly effective for monitoring of manufacturing processes [26]. According to the DDS methodology, a process can be approximated by an ARMA (Auto-Regressive Moving-Average) model:

$$\mathbf{y}_t - \Phi_1\mathbf{y}_{t-1} - \dots - \Phi_n\mathbf{y}_{t-n} = \mathbf{a}_t - \theta_1\mathbf{a}_{t-1} - \dots - \theta_{n-1}\mathbf{a}_{t-n+1} \qquad \mathbf{(2)}$$

where, $\mathbf{a}_t \sim \mathbf{NID}(0, \sigma_a^2)$ is white noise, Φ_i and θ_i are parameter matrices, and the order of the model, *n* can be determined through a systematic procedure. In comparison to the other modeling techniques, the DDS methodology often provides a better description for the process. In addition, based on the ARMA model, more accurate spectrum estimation can be obtained [27].

When a model is found, monitoring can be performed by detecting the changes of the model parameters (e.g., damping ratio and natural frequency) and/or the changes of expected system responses (e.g., prediction error). Model-based monitoring methods are also referred to as failure detection methods. Nevertheless, model-based methods have two significant limitations. First, many manufacturing processes are nonlinear time-variant systems. A typical example is machining processes, where the nonlinearity is caused by the regenerate interaction between the structure vibration and the cutting forces [28]. Although adaptation schemes may be used, model-based methods are usually less effective to the structural change of the process. Second, sensor signals are dependent on process working conditions. It is often difficult to identify whether a change in sensor signals is due to the change of process working condition or is due to the deterioration of the process [15].

3.1.2. Feature-based monitoring methods

Feature-based monitoring methods use suitable features of the sensor signals to identify the process conditions. Given a sensor signal, $\mathbf{y}_t$ (t = 1, 2, ...), the feature(s) of the sensor signal, called monitoring index(s), can be represented by:

$$\mathbf{X} = \mathbf{P}(\mathbf{y}_t) \qquad (3)$$

where, P(•) is an operator. These features could be time and/or frequency domain features of the sensor signals such as mean, variance, skewness, kurtosis, crest factor, power in a specified frequency band. A special case is

$$\mathbf{x} = \mathbf{P}(\mathbf{y}_t) = \mathbf{y}_t \qquad (4)$$

at which the monitoring index is the sensor signal itself. Often, normalized indices (the indices that are independent of unit) are recommended [29]. In general, the operator, P(•), may be time-dependent, nonlinear, or even in unanalysable form. As a result, monitoring indices may be continuous numbers (e.g., the mean of a sensor signal), or discrete events (e.g., a logical signal "on" and "off"). The process working conditions (e.g., the cutting speed in a machining process) can also be used as monitoring indices.

Obviously, choosing appropriate monitoring indices is crucial. Ideally, the monitoring indices should be: (a) sensitive to the process health conditions, (b) insensitive to the process working conditions, and (c) cost effective. In practice, monitoring indices should be selected based on analytical study and computer simulation of the process, as well as systematic experiments. However, in many applications, monitoring index selection remains an art. The selection of appropriate monitoring indices often involves various signal processing techniques.

When a monitoring index is obtained, monitoring can be done by the simple condition statement below:

$$\textbf{if } x < t_r \textbf{ then normal else abnormal} \qquad (5)$$

In many applications, however, the threshold cannot be completely distinguished among various process conditions. Hence, determining the threshold is important. In general, the threshold may be determined using hypothesis testing method [30]. If the process failure is evolutionary in nature such as wear and fatigue, then one can use the Pareto distribution method [31], or the varying threshold method [32]. If the monitoring index is strongly correlated to process working conditions, then an empirical threshold estimation method is recommended [33].

The more effective way is to use multiple sensor signals and multiple monitoring indices. This is also referred to as sensor fusion, classification, or decision-making [34][35].

Monitoring tasks may be different from application to application. However, the basic forms of these tasks are remarkably similar. Assuming that the monitoring indices, $\mathbf{x} = \{x_1, x_2, ..., x_m\}$, have been defined and calculated, and the process conditions, $\mathbf{h} = \{h_1, h_2, \ldots, h_n\}$, are also defined, then there exists a relationship between the process conditions and the monitoring indices as shown in **Figure 3-1**. Mathematically, this is represented as:

$$\mathbf{Q}: \mathbf{h} \rightarrow \mathbf{x} \qquad \textbf{(6)}$$

where, **Q** is called the relationship. It should be noted that the relationship might be in different forms such as analytical function, a pattern, a fuzzy system, a decision tree, a neural network, or an expert system.

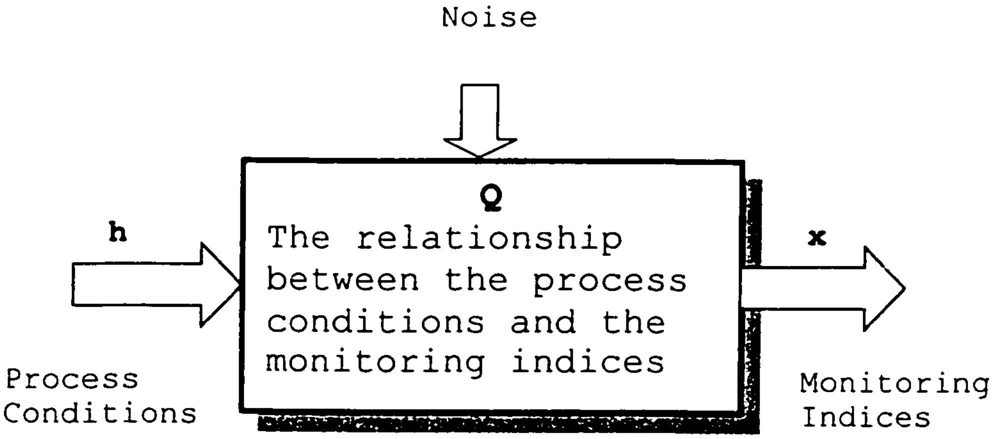


Figure 3-1 General model for monitoring of manufacturing process

As it was indicated at beginning, the feature-based methods consist of two phases: learning and classification. Learning, also called training, is to establish the relationship, **Q**. There are two types of learning methods: learning from samples and learning from instructions. For monitoring of manufacturing processes, learning from samples is usually more effective since precise instructions are typically unavailable or rather limited. In general, learning samples can be organized as shown in **Table 3-1** where, m is the number of monitoring indices, n is the number of process conditions, and N is the number of available learning samples. Also, $\mathbf{x}_k=[x(k, 1)\ x(k, 2), \ldots, x(k, m)]$ denotes the kth learning, and $h(\mathbf{x}_k)\in\{ h_1, h_2, \ldots, h_n\}$ implies that the kth learning sample is obtained at one of the known process conditions: $h_1, h_2, \ldots, h_n$.

For convenience, i will be used to indicate the variation of the monitoring indices, j will be used to indicate the variation of the process conditions, and k will be used to indicate the variation of the learning samples. Also, capital letters will be used for variables, small letters for the values of the variables, bold letters for vectors, and fancy letters for sets unless otherwise stated. Based on the learning samples, the relationship can be established as discussed in subsequent sections.

Table 3-1 The Learning Samples

Samples	Monitoring Indices						Process conditions
	X_1	X_2	…	X_i	…	X_m	
$\mathbf{x}_1$	x(1,1)	x(1,2)	…	x(1,i)	…	x(1,m)	$h(\mathbf{x}_1) \in (h_1, h_2, \ldots, h_n)$
$\mathbf{x}_2$	x(2,1)	x(2,2)	…	x(2,i)	…	x(2,m)	$h(\mathbf{x}_2) \in (h_1, h_2, \ldots, h_n)$
…	…	…	…	…	…	…	
$\mathbf{x}_N$	x(N,1)	x(N,2)	…	x(N,i)	…	x(N,m)	$h(\mathbf{x}_N) \in (h_1, h_2, \ldots, h_n)$

In the classification phase, based on the relationship, **Q**, and the new sample, **x**, the estimated process condition is identified by the inverse operation of equation (6):

$$\mathbf{Q}^{-1} : \mathbf{x} \rightarrow \mathbf{h} \tag{7}$$

Depending on the form of the relationship, the inverse operation may be pattern match, or decision tree search, etc.

Clearly, different relationship results in different methods. According to literature, a large number of methods have been developed for monitoring of manufacturing processes. It is unclear, however, which method performs best [15]. In fact, most of the literature only shows that a specific method works for a specific application. The performances of the method in terms of success rate, sensitivity, and robustness are typically not investigated. Various feature-based monitoring methods include: (a) expert systems, (b) pattern recognition, (c) fuzzy systems, (d) decision trees, and (e) neural networks. The engineering relevance of the study is to develop a generic computer automated system for monitoring of various manufacturing processes [15].

3.2 The application of monitoring methods in chip size monitoring

As it was indicated in the Chapter 1, the deep-hole machining processes have many uncertain factors, and there are no efficient algorithmic solutions to control them. Based on the monitoring methods discussed above, it is not a good idea to use model-based monitoring methods for chip size monitoring, because it will be difficult to find efficient algorithmic solutions. Therefore, the solution cannot be found with conventional programming methods. The feature-based monitoring method has become a more suitable method for chip size monitoring.

It is also known that the expert control system is believed a promising solution to the deep-hole machining problems. For the same reasons the chips' size monitoring in deep-hole machining can also use expert system as the monitoring method. The knowledge for chip size monitoring can be obtained from human expert and from appropriate experiments, and can be updated automatically in the application.

3.3 Definition of Chip Size Conditions and Monitoring Indices

In general, the success of machining process condition monitoring depends not only on monitoring methods, but also on other issues such as sensing, sensor signal processing and computer implementation.

An inductive proximity sensor is used in the monitoring system of chip size. It can output digital signals like an electrical switch and send the signals to a computer. The signals can be processed to get the frequency of chip occurrence by the computer. The chip size is most important information for knowing chips situation. According to the feature-based monitoring method the relationship of frequency of chips occurrence and chips size have to be established. Clearly the chips size can be defined as the process conditions $\mathbf{h}$, and the frequency of chips flow can be defined as the monitoring index $\mathbf{x}$.

According to the definition of equation (3), monitoring index $\mathbf{x}$ should be

$$\mathbf{x} = \mathbf{P}(\mathbf{y}_i)$$

$\mathbf{y}_i$ is the sensor signals. The frequencies of chips occurrence **x** can be obtained through signal process and calculation.

The purpose of setting up the chip size monitoring system is not getting the chips' size exactly. It is used to find the status of the chips if they are acceptable or unacceptable for the requirements of deep-hole machining. Therefore, the chips conditions are defined in **Table 3-2**.

Table 3-2 Definition of chips conditions

Class **h**	Chips condition Average Length (**AL**)	Definition
H_1	<= 15 mm	Desired length
H_2	< 20 mm	Acceptable length
H_3	> 20 mm	Unacceptable length

Similarly as the monitoring indices the frequency can be defined in **Table 3-3**.

Table 3-3 Definition of monitoring indices

Index **x**	Definition
X_1	original frequency of chips flow (**OF**) 7Hz < f < 25 Hz
X_2	Total mean of frequency (**TM**)
X_3	Mean of frequency in 5 seconds (**SM**)

Table 3-4 Learning samples for chips' size monitoring

Learning samples (v = 99 m/min)		**Indices** (frequencies Hz)			**Process condition** chips length (mm)
No.	Feed rate (mm/min)	Original **OF**	Total mean **TM**	5s mean **SM**	Average length **AL**
1	23.96	The frequency varies in each test. This monitoring index is used to find zero points if they are continuous in 3 seconds.	6.49	The mean frequency in each 5 seconds varies in each test. This monitoring index is used to find the points if they are continuously acceptable or unacceptable in 5 seconds.	31.39
2	28		6.92		32.67
3	24.28		6.95		19.26
4	21.55		7.16		53.25
5	22.72		7.63		27.6
6	29.76		8.28		17.8
7	25.13		8.36		23.52
8	23.96		8.4		22.66
9	25.56		8.75		20.44
10	26.24		8.86		17.67
11	30.93		9.12		14.06
12	28.59		9.3		17.29
13	29.04		9.71		14.07
14	30.35		9.71		15.74
15	27.44		10.23		15.14
16	33.87		11.27		15.53
17	36.8		13.12		15
18	39.73		14.21		13.75
19	52.64		14.26		10.2
20	45.6		14.39		12.93
21	51.47		17.21		10.4
learning samples (v = 88 m/min)					
22	22.13		7.73		20.9
23	28		11.75		18.27
24	33.87		12.9		15.59
25	39.73		13.43		12.16
26	30.93		13.6		16.75
27	36.8		13.81		13.81
28	42.67		14.55		11.08
29	45.6		14.7		11.28
30	48.53		14.9		10.85
31	50.29		17.55		10.62
32	51.47		20.33		11.11

For monitoring of machining processes, learning from samples is usually more effective since precise instructions are typically unavailable or rather limited. Total of 32 learning samples were obtained from the experiments in two groups.

Chapter 4

Analysis of Experimental Results

4.1 Experiment Data Analysis and Signal processing

The signals were recorded during the experiments for each drilling. Four learning samples are used for data analysis to find the appropriate methods for data process. The samples used for analysis represent the situations of threshold in experiments. These were used because the experiments show that the frequency of chips flow is strongly correlated to the chips size.

The two samples have shortest mean length of chips in the experiments with closed feed rate and different cutting speed. The other two have longest mean length of chips with similar cutting conditions. All the data of samples are listed in the **Table 4-1**, **Table 4-2**, **Table 4-3**, and Table **4-4**. The followed figures are their expression of diagram of curves.

According to working principle of the Inductive Proximity Sensor, the signals from sensor can be counted with the

Table 4-1 Experiment Data (Cutting speed = 88 m/min, Feed = 22.13 mm/min)

	Frequency (Hz)				
Time (s)	Original	Mean of Total	Mean of 3 seconds	Mean of 4 seconds	Mean of 5 seconds
1	5	5			
2	6	5.5			
3	7	6	6		
4	7	6.25	6.666667	6.25	
5	8	6.6	7.333333	7	6.6
6	9	7	8	7.75	7.4
7	8	7.142857	8.333333	8	7.8
8	9	7.375	8.666667	8.5	8.2
9	8	7.444444	8.333333	8.5	8.4
10	11	7.8	9.333333	9	9
11	9	7.909091	9.333333	9.25	9
12	8	7.916667	9.333333	9	9
13	9	8	8.666667	9.25	9
14	11	8.214286	9.333333	9.25	9.6
15	7	8.133333	9	8.75	8.8
16	10	8.25	9.333333	9.25	9
17	8	8.235294	8.333333	9	9
18	6	8.111111	8	7.75	8.4
19	1	7.736842	5	6.25	6.4
20	12	7.95	6.333333	6.75	7.4
21	10	8.047619	7.666667	7.25	7.4
22	7	8	9.666667	7.5	7.2
23	9	8.043478	8.666667	9.5	7.8
24	11	8.166667	9	9.25	9.8
25	7	8.12	9	8.5	8.8
26	12	8.269231	10	9.75	9.2
27	10	8.333333	9.666667	10	9.8
28	7	8.285714	9.666667	9	9.4
29	8	8.275862	8.333333	9.25	8.8
30	9	8.3	8	8.5	9.2
31	13	8.451613	10	9.25	9.4
32	10	8.5	10.66667	10	9.4
33	7	8.454545	10	9.75	9.4
34	4	8.323529	7	8.5	8.6
35	6	8.257143	5.666667	6.75	8
36	1	8.055556	3.666667	4.5	5.6
37	6	8	4.333333	4.25	4.8
38	4	7.894737	3.666667	4.25	4.2
39	2	7.74359	4	3.25	3.8
40	9	7.775	5	5.25	4.4
41	5	7.707317	5.333333	5	5.2
42	11	7.785714	8.333333	6.75	6.2
43	7	7.767442	7.666667	8	6.8
44	6	7.727273	8	7.25	7.6

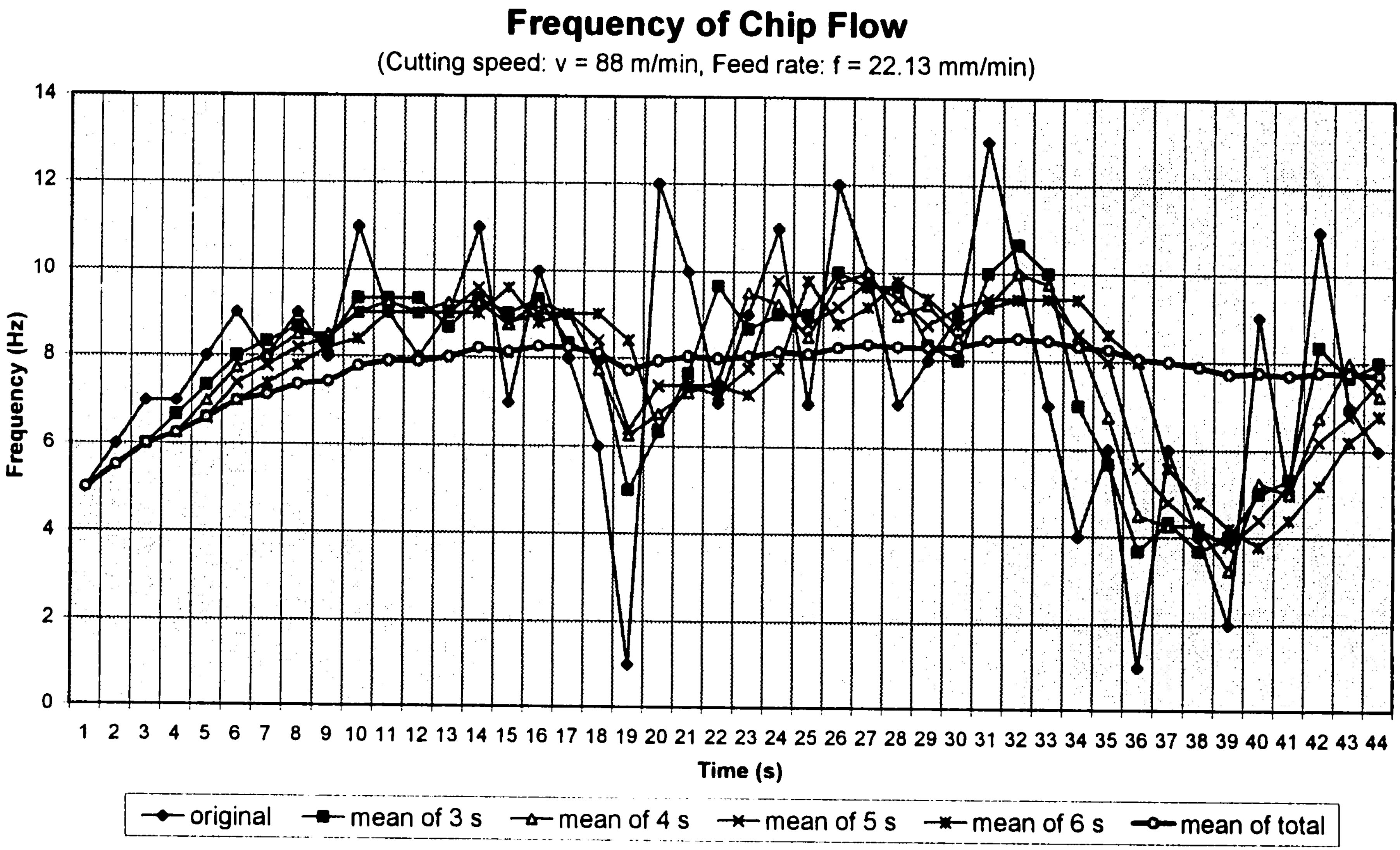


Figure 4-1 Frequency of chip flow (cutting speed v = 88 m/min, feed rate f = 22.13 mm/min)

Chips' length distribution

Chips' length (mm)	%
Chips>50	12
>30	18
>20	20
>15	22
<15	28

Sample of chips

1. 40% unacceptable, 42% acceptable, 28% ideal
2. Total mean of frequency is 7.73 Hz.
3. Average length is 20.9 mm.
4. Unacceptable

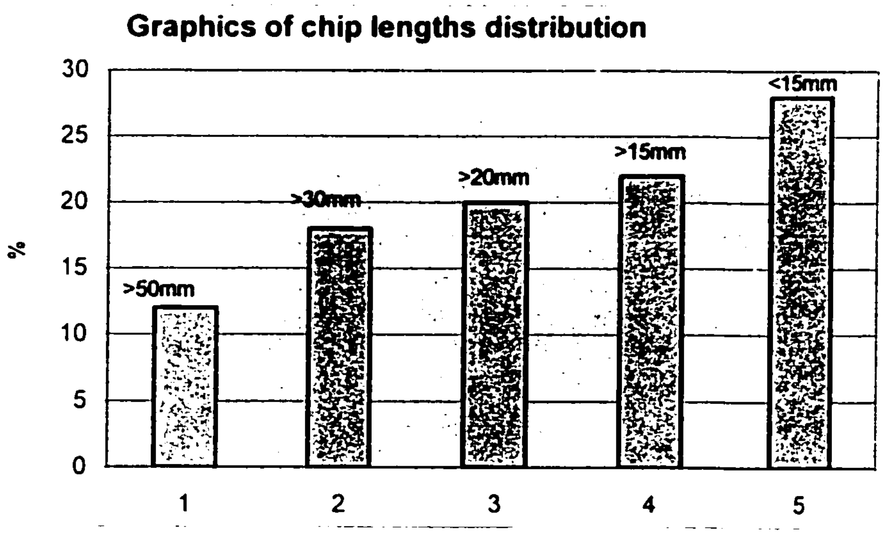


Figure 4-2 Distribution of chip lengths

(cutting speed v = 88 m/min, feed rate f = 22.13 mm/min)

Table 4-2 Experiment Data (Cutting speed = 99 m/min, Feed = 21.55 mm/min)

	Frequency					
Time (s)	Original	Sum	Mean	Mean of 3 seconds	Mean of 4 seconds	Mean of 5 seconds
1	8	8	8			
2	7	15	7.5			
3	7	22	7.333333	7.333333		
4	8	30	7.5	7.333333	7.5	
5	6	36	7.2	7	7	7.2
6	6	42	7	6.666667	6.75	6.8
7	7	49	7	6.333333	6.75	6.8
8	7	56	7	6.666667	6.5	6.8
9	10	66	7.333333	8	7.5	7.2
10	10	76	7.6	9	8.5	8
11	8	84	7.636364	9.333333	8.75	8.4
12	5	89	7.416667	7.666667	8.25	8
13	7	96	7.384615	6.666667	7.5	8
14	6	102	7.285714	6	6.5	7.2
15	5	107	7.133333	6	5.75	6.2
16	6	113	7.0625	5.666667	6	5.8
17	4	117	6.882353	5	5.25	5.6
18	8	125	6.944444	6	5.75	5.8
19	7	132	6.947368	6.333333	6.25	6
20	7	139	6.95	7.333333	6.5	6.4
21	3	142	6.761905	5.666667	6.25	5.8
22	9	151	6.863636	6.333333	6.5	6.8
23	9	160	6.956522	7	7	7
24	6	166	6.916667	8	6.75	6.8
25	6	172	6.88	7	7.5	6.6
26	5	177	6.807692	5.666667	6.5	7
27	6	183	6.777778	5.666667	5.75	6.4
28	7	190	6.785714	6	6	6
29	6	196	6.758621	6.333333	6	6
30	8	204	6.8	7	6.75	6.4
31	8	212	6.83871	7.333333	7.25	7
32	7	219	6.84375	7.666667	7.25	7.2
33	7	226	6.848485	7.333333	7.5	7.2
34	7	233	6.852941	7	7.25	7.4
35	6	239	6.828571	6.666667	6.75	7
36	5	244	6.777778	6	6.25	6.4
37	6	250	6.756757	5.666667	6	6.2
38	9	259	6.815789	6.666667	6.5	6.6
39	7	266	6.820513	7.333333	6.75	6.6
40	5	271	6.775	7	6.75	6.4
41	8	279	6.804878	6.666667	7.25	7
42	8	287	6.833333	7	7	7.4
43	6	293	6.813953	7.333333	6.75	6.8
44	4	297	6.75	6	6.5	6.2

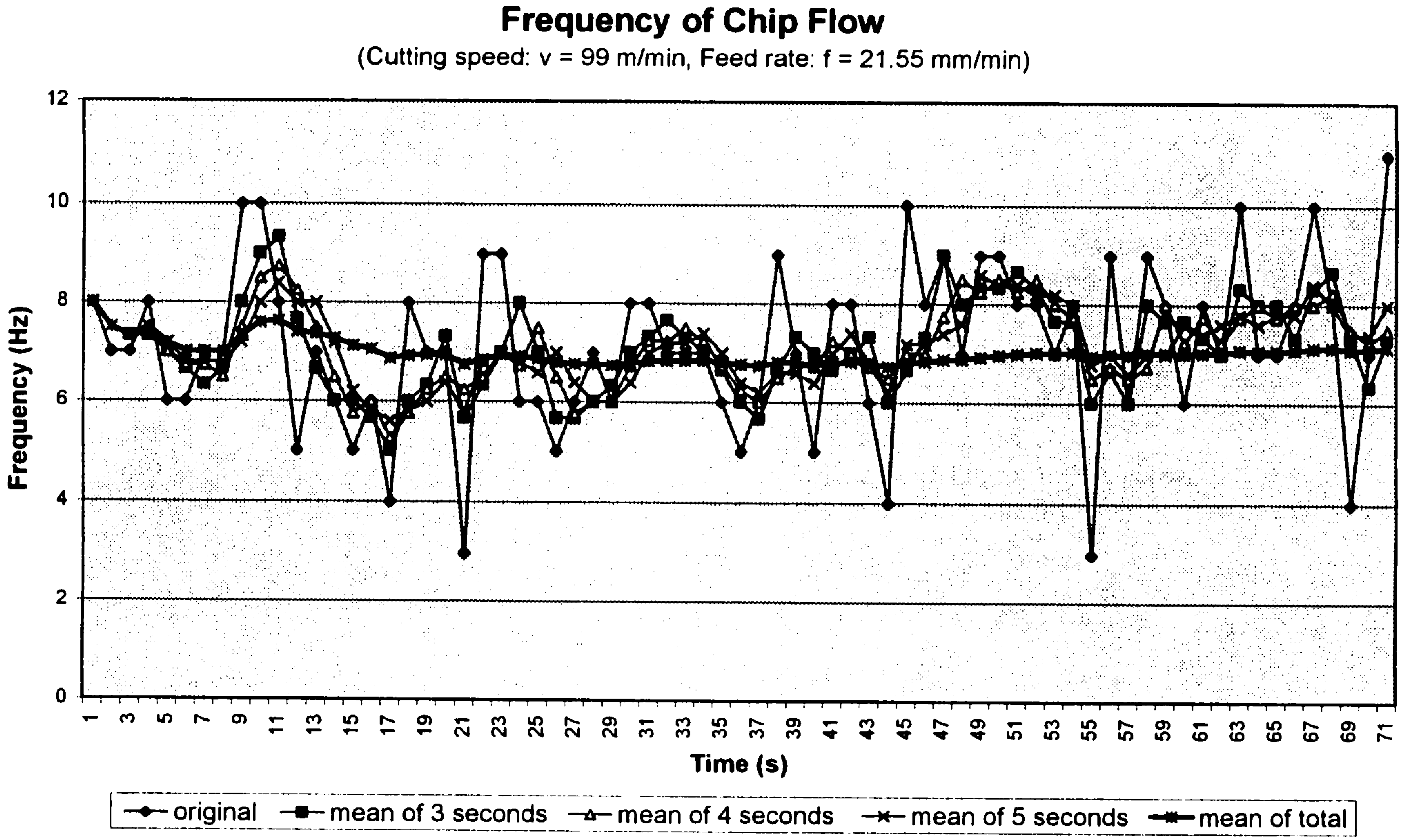
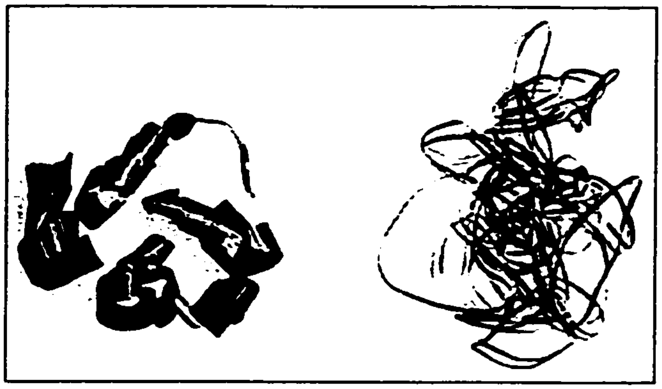


Figure 4-3 Frequency of chip flow (cutting speed v = 99 m/min, feed rate f = 21.55 mm/min)

Chips' length distribution

Chips' length (mm)	%
>100	7.5
>70	32.5
>50	25
>30	22.5
<30	12.5



1. 88% unacceptable, 12% acceptable
2. Total mean of frequency 7.15 Hz.
3. Average length 53.3 mm
4. **Unacceptable**

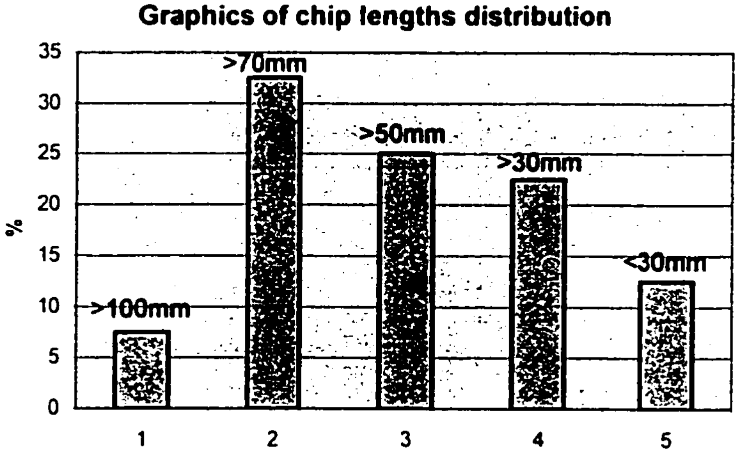


Figure 4-4 Distribution of chip lengths

(cutting speed v = 99 m/min, feed rate f = 21.55 mm/min)

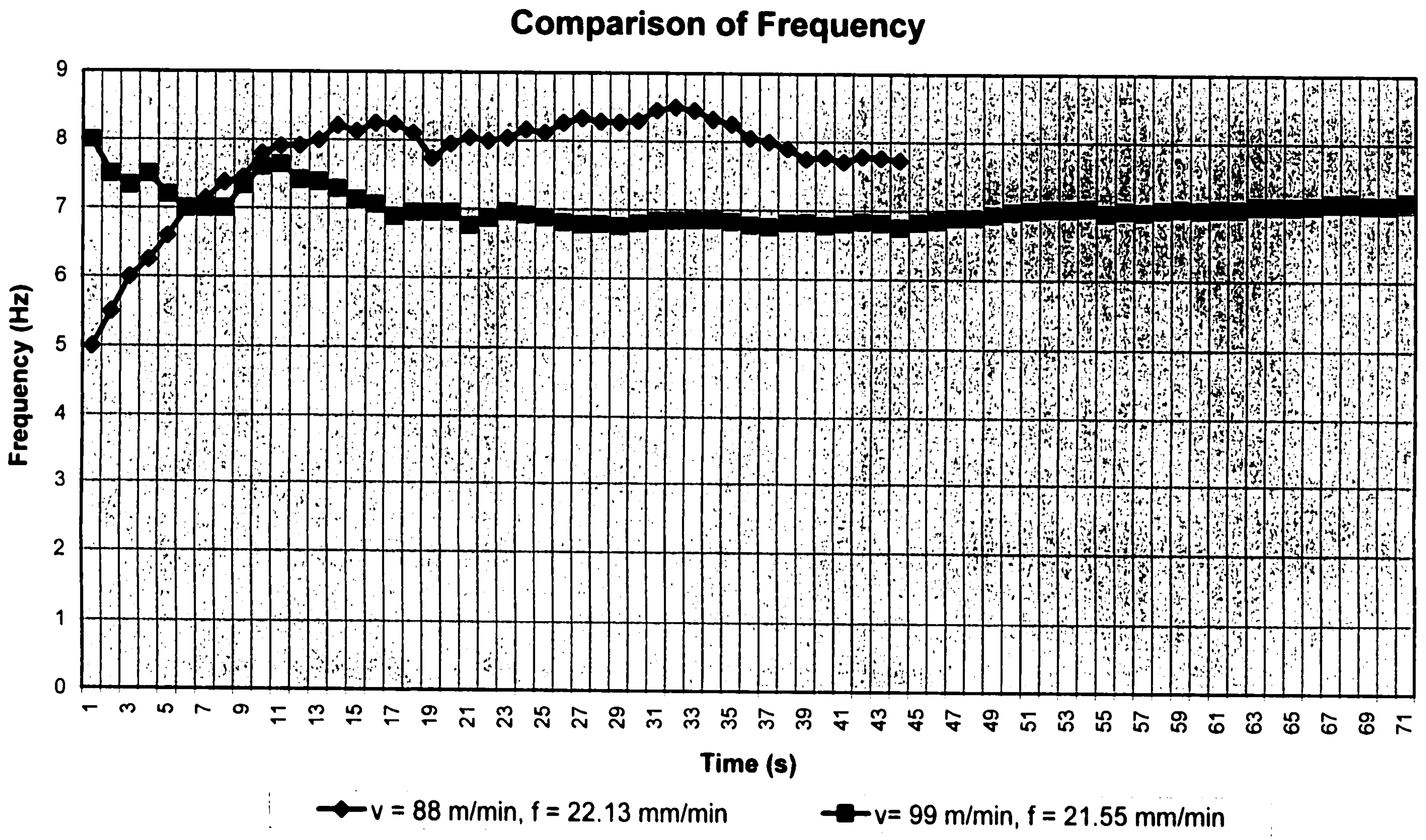


Figure 4-5 Comparison of frequency

Table 4-3 Experiment Data (Cutting speed = 88 m/min, Feed = 51.47 mm/min)

	Frequency				
Time (s)	Original	Mean of 2 seconds	Mean of 3 seconds	Mean of 4 seconds	Mean of 5 seconds
1	4	4			
2	16	10			
3	18	12.66667	12.66667		
4	19	14.25	17.66667	14.25	
5	23	16	20	19	16
6	23	17.16667	21.66667	20.75	19.8
7	26	18.42857	24	22.75	21.8
8	17	18.25	22	22.25	21.6
9	21	18.55556	21.33333	21.75	22
10	23	19	20.33333	21.75	22
11	20	19.09091	21.33333	20.25	21.4
12	22	19.33333	21.66667	21.5	20.6
13	31	20.23077	24.33333	24	23.4
14	23	20.42857	25.33333	24	23.8
15	23	20.6	25.66667	24.75	23.8
16	18	20.4375	21.33333	23.75	23.4
17	20	20.41176	20.33333	21	23
18	21	20.44444	19.66667	20.5	21
19	19	20.36842	20	19.5	20.2
20	24	20.55	21.33333	21	20.4
21	25	20.7619	22.66667	22.25	21.8
22	22	20.81818	23.66667	22.5	22.2
23	15	20.56522	20.66667	21.5	21
24	25	20.75	20.66667	21.75	22.2
25	21	20.76	20.33333	20.75	21.6
26	0	19.96154	15.33333	15.25	16.6
27	23	20.07407	14.66667	17.25	16.8
28	25	20.25	16	17.25	18.8
29	23	20.34483	23.66667	17.75	18.4
30	20	20.33333	22.66667	22.75	18.2

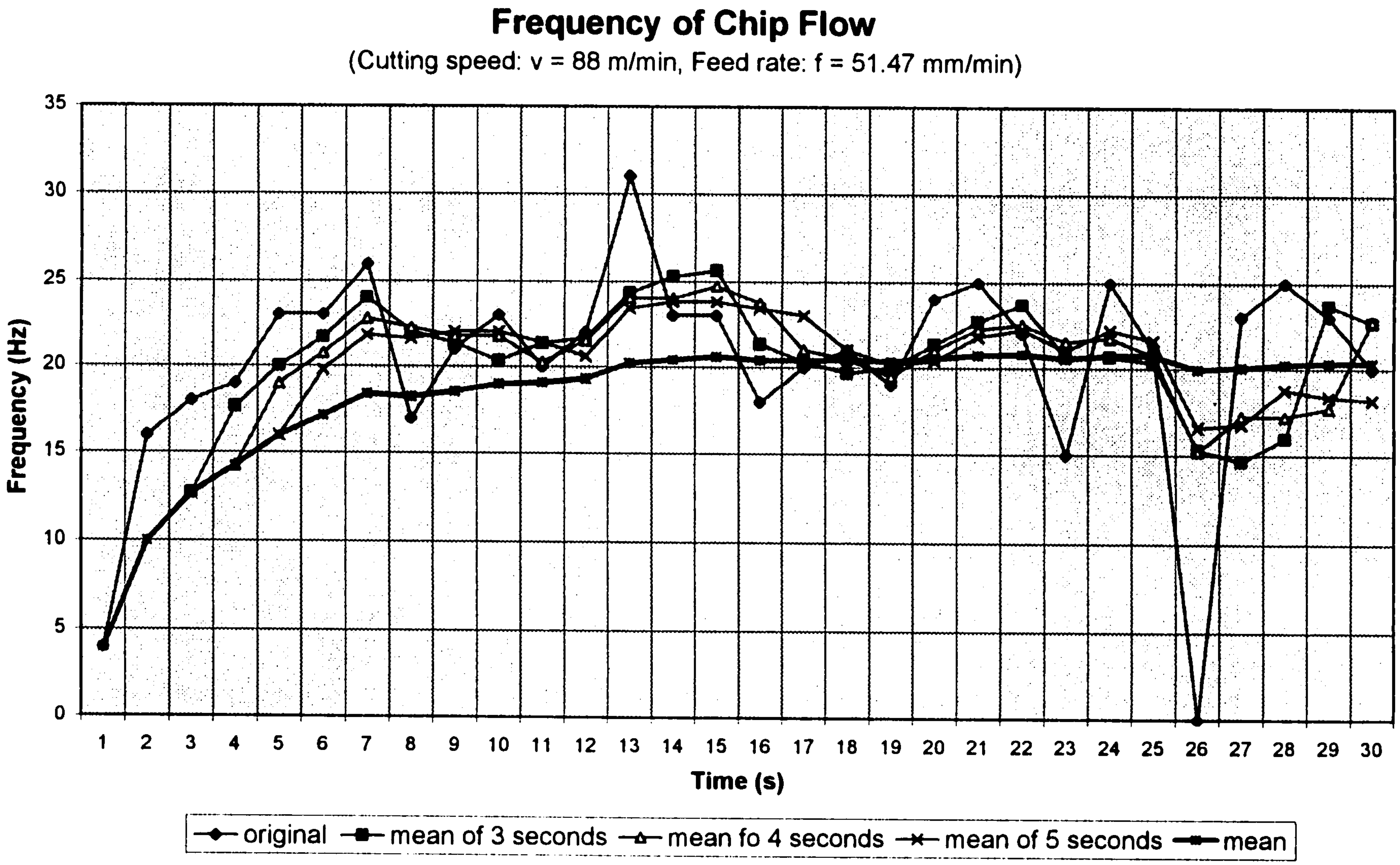
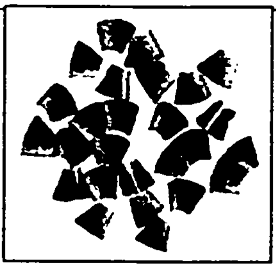


Figure 4-6 Frequency of chip flow (cutting speed v = 88 m/min, feed rate f = 51.47 mm/min)

Chips' length distribution

Chips' length (mm)	%
<25	5
>15	4.5
>11	60
>9	22.5
<9	8



Sample of chips

1. 10% acceptable, 90% ideal
2. Total mean of frequency is 20.33 Hz.
3. Average length is 11.11 mm.
4. **acceptable**

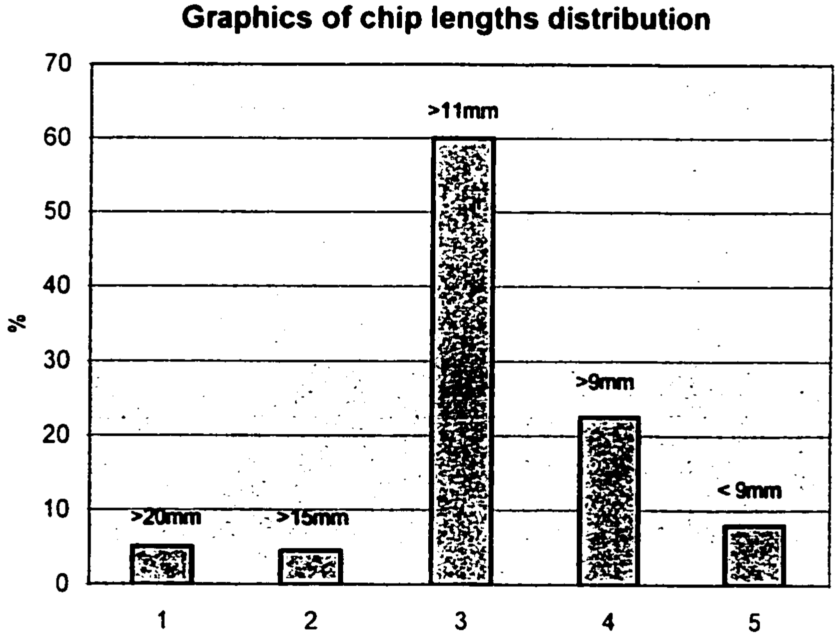

Graphics of chip lengths distribution

Figure 4-7 Distribution of chip lengths

(Cutting speed = 88 m/min, Feed = 51.47 mm/min)

Table 4-4 Experiment Data (Cutting speed = 99 m/min, Feed = 51.47 mm/min)

	Frequency					
Time (s)	Original	Sum	Mean	Mean of 3 3 seconds	Mean of 3 4 seconds	Mean of 3 5 seconds
1	19	19	19			
2	13	32	16			
3	19	51	17	17		
4	18	69	17.25	16.66667	17.25	
5	16	85	17	17.66667	16.5	17
6	21	106	17.66667	18.33333	18.5	17.4
7	14	120	17.14286	17	17.25	17.6
8	17	137	17.125	17.33333	17	17.2
9	21	158	17.55556	17.33333	18.25	17.8
10	12	170	17	16.66667	16	17
11	19	189	17.18182	17.33333	17.25	16.6
12	16	205	17.08333	15.66667	17	17
13	18	223	17.15385	17.66667	16.25	17.2
14	17	240	17.14286	17	17.5	16.4
15	18	258	17.2	17.66667	17.25	17.6
16	21	279	17.4375	18.66667	18.5	18
17	18	297	17.47059	19	18.5	18.4
18	19	316	17.55556	19.33333	19	18.6
19	19	335	17.63158	18.66667	19.25	19
20	0	335	16.75	12.66667	14	15.4
21	19	354	16.85714	12.66667	14.25	15
22	18	372	16.90909	12.33333	14	15
23	18	390	16.95652	18.33333	13.75	14.8
24	20	410	17.08333	18.66667	18.75	15
25	25	435	17.4	21	20.25	20
26	16	451	17.34615	20.33333	19.75	19.4
27	17	468	17.33333	19.33333	19.5	19.2
28	15	483	17.25	16	18.25	18.6
29	16	499	17.2069	16	16	17.8

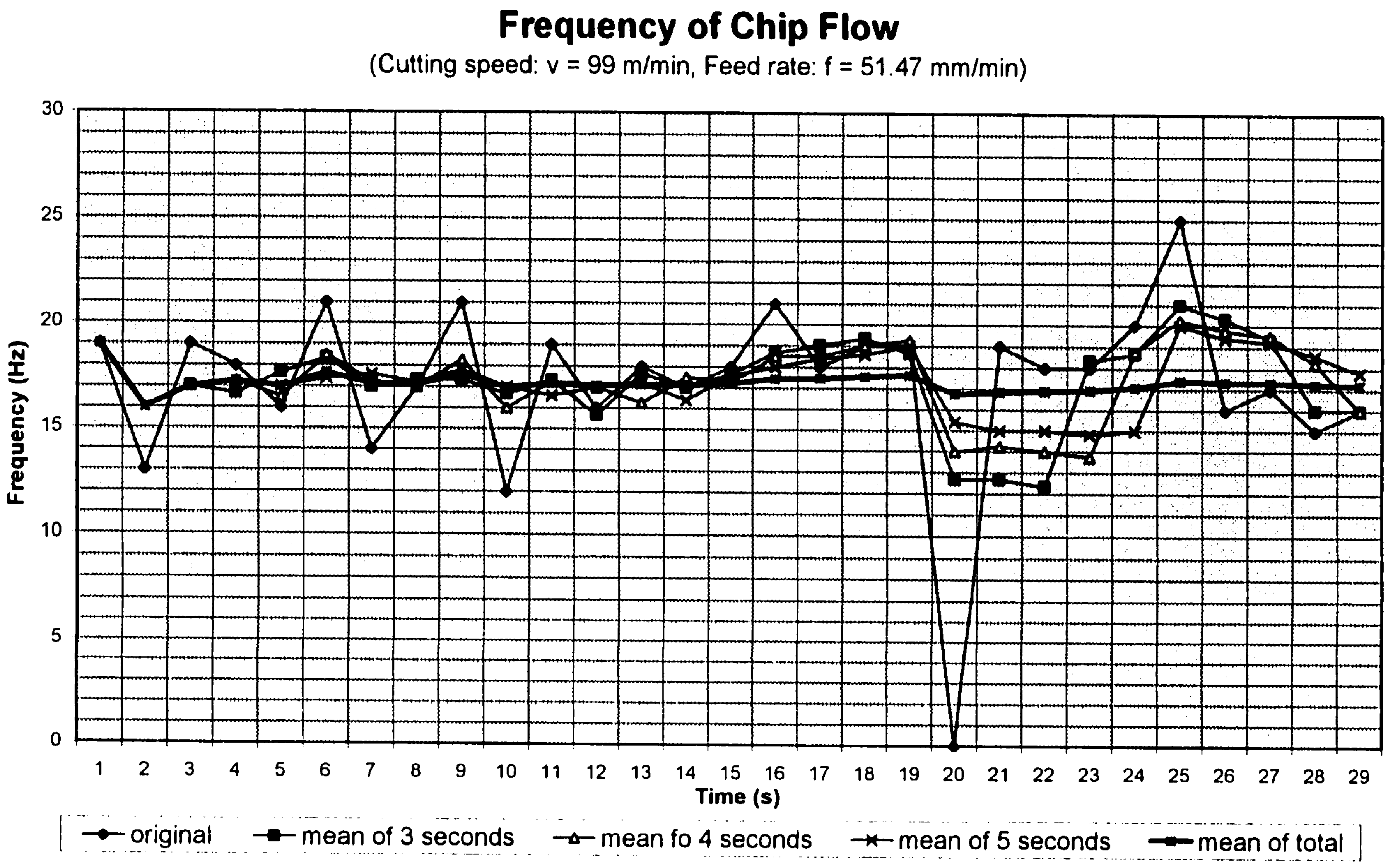
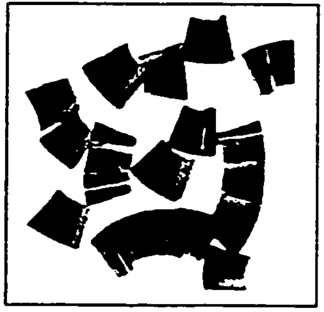


Figure 4-8 Frequency of chip flow (cutting speed v = 99 m/min, feed rate f = 51.47 mm/min)

Chips' length distribution

Chips' length (mm)	%
<25	2.2
>15	3.6
>10	36.7
<10	57.5



Sample of chips

1. 6% acceptable, 94% ideal
2. Total mean of frequency Hz.
3. Average length mm.
4. acceptable

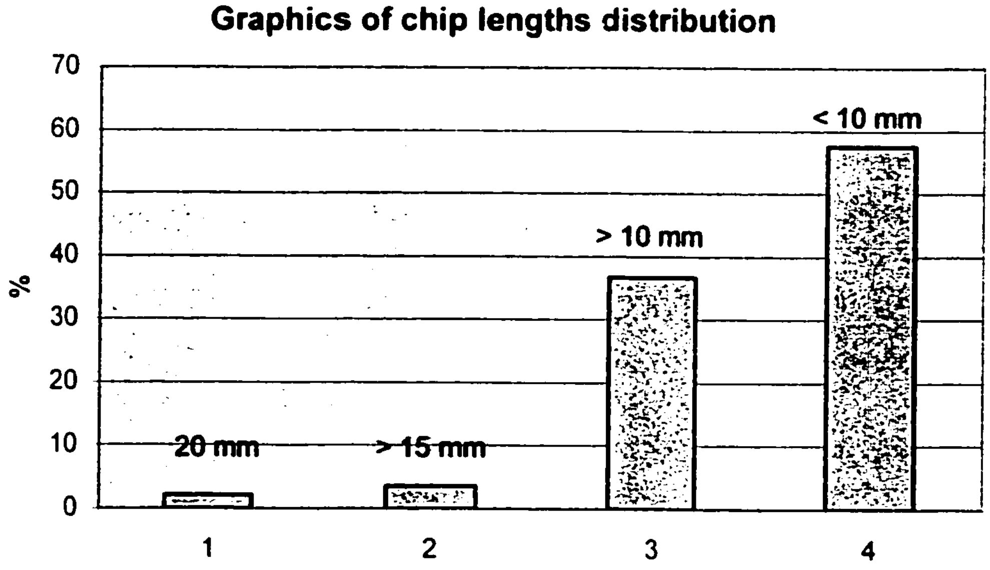


Figure 4-9 Distribution of chip lengths

(Cutting speed = 99 m/min, Feed = 51.47 mm/min)

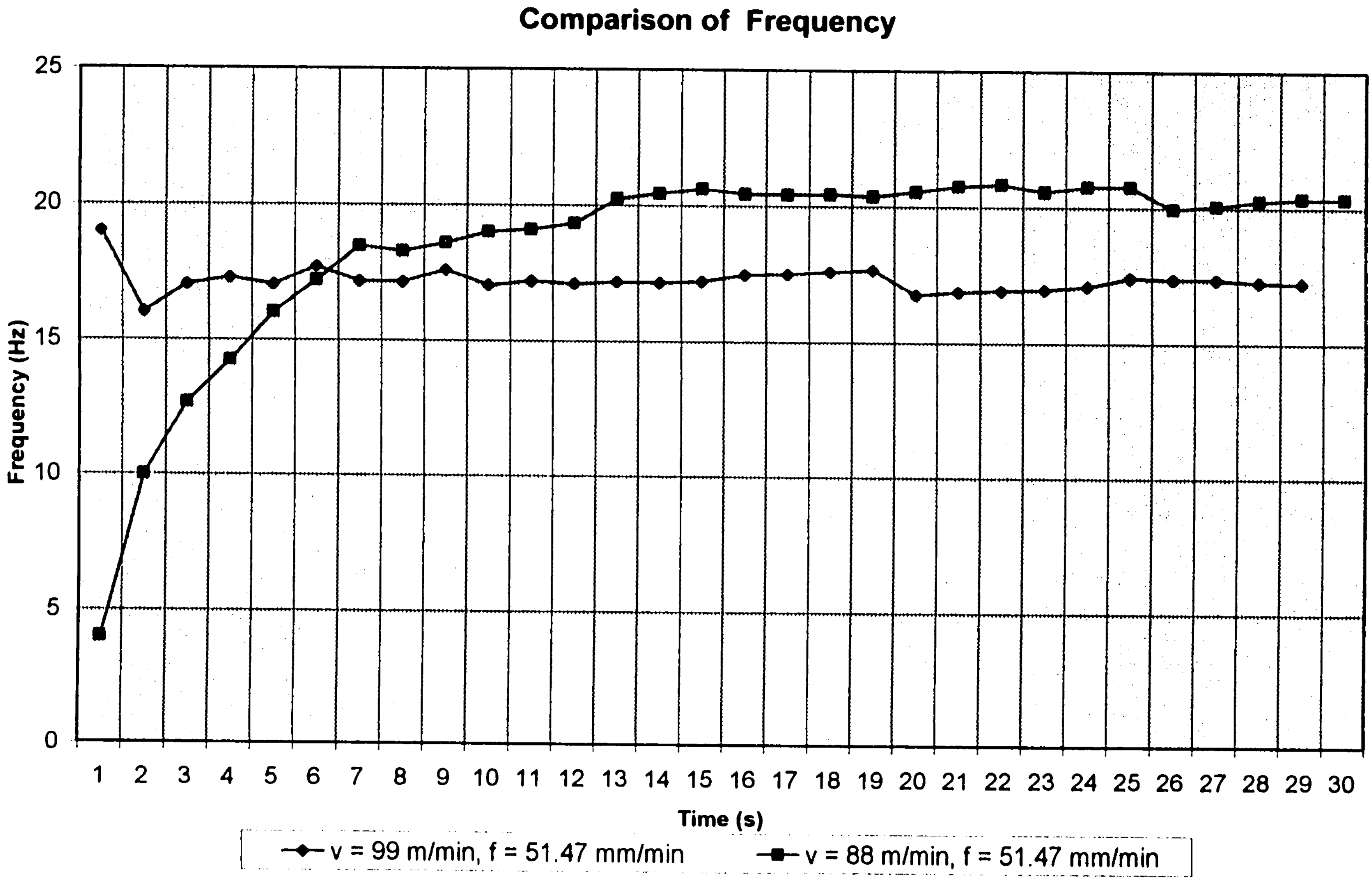


Figure 4-10 Comparison of frequency

program in each second to get the original frequencies(**OF**) of chips flow. At least three different situations can be distinguished from the original frequency. One shows normal situation with some values of frequency. Other two show the special situations when the frequencies become to zero. There are two possibilities in the case of zero frequency. When the sensor output is always 0 signal that means there are no chips flowing to the front of sensor. When the sensor output is always 1 signal that means the chips clog at the front area of sensor.

It is known that in the deep-hole machining process there are always some uncertainty factors. Even they can be identified from monitoring chip flow. From **Figure 4-1, Figure 4-3, Figure 4-6, and Figure 4-8** it can be found that the frequencies within machining conditions vary over a wide range, and hence it is not good to use them as a monitoring index to determine chips length. But it can be found also that most of them are close to a mean value of frequencies, and extreme points, such as 0, are insulated from two or three. In addition, for most of total mean (**TM**) lines the frequencies vary within a narrow range after around 10 seconds. That means the frequency of chips flow can serve as stable information for determining the chips length. The value of total mean of frequency can be represented by

$$x_n = \frac{\sum_{1}^{n} y_i}{n} \qquad (i = 1, 2, \ldots, n) \qquad \textbf{(8)}$$

where $\mathbf{x_n}$ is the total mean of frequency over **n** seconds, $\mathbf{y_i}$ is sensor signal.

Comparing **Figure 4-1** and **Figure 4-3** it is clear that low feed rate has low frequencies of chips flow, and high feed rate has high frequencies of chips flow, under same cutting speed. The same result can be obtained from the comparison of **Figure 4-6** and **Figure 4-8**. The two curves of total mean of frequencies, with same feed rate and different cutting speed (s = 88 m/min and 99 m/min, f = 51.47 mm/min), are put together in **Figure 4-10** to compare the difference of frequencies under two machining conditions. In general, under same feed rate low cutting speed should generate high frequencies of chips flow and high cutting speed should generate low frequencies of chips flow. In **Figure 4-10** the corrected experiment result is shown. The same result can be found in **Figure 4-5,** but the feed rates are closed and lower. All the figures discussed above show that the frequency of chips flow could provide correct information to determine the chips length.

The total mean of frequencies of chips flow gives reasonable information in normal situation. It can be used as one of monitoring indices, but it cannot serve as complete information we need for monitoring. In general, the deep-hole machining process takes at least few minutes to finish the machining job. In the meantime, it is possible if some special things happened in few seconds. The total mean of frequency can hide the special case in few seconds because huge numbers can be generated in the minutes. Therefore, the mean of frequencies within seconds should be monitored to get instant information of chips flow. In the **Figure 4-1** the means of frequencies of 3 seconds to 6 seconds are indicated. From data analysis and referring to all other data from experiments in different cutting conditions the mean of frequencies in 5 seconds (**SM**) is considered to be another monitoring index for instant monitoring of chips flow. The value of 5 seconds mean of frequency can be represented by

$$x_n = \frac{\sum_{n-4}^{n} y_i}{5} \qquad (i = n-4,\ n-3,\ \ldots,\ n \text{ and } n = 1,\ 2,\ 3,\ \ldots) \qquad \mathbf{(9)}$$

where $\mathbf{x}_\mathbf{n}$ is the 5 seconds mean of frequency at each **n** second, $\mathbf{y}_\mathbf{i}$ is sensor signal.

When sensor signals are sent to computer the data processing program runs to process data to get: (1) original frequencies, (2) total mean of frequencies, and (3) mean of frequencies in 5 seconds in each second during machining. Then the information is sent to expert system for decision making.

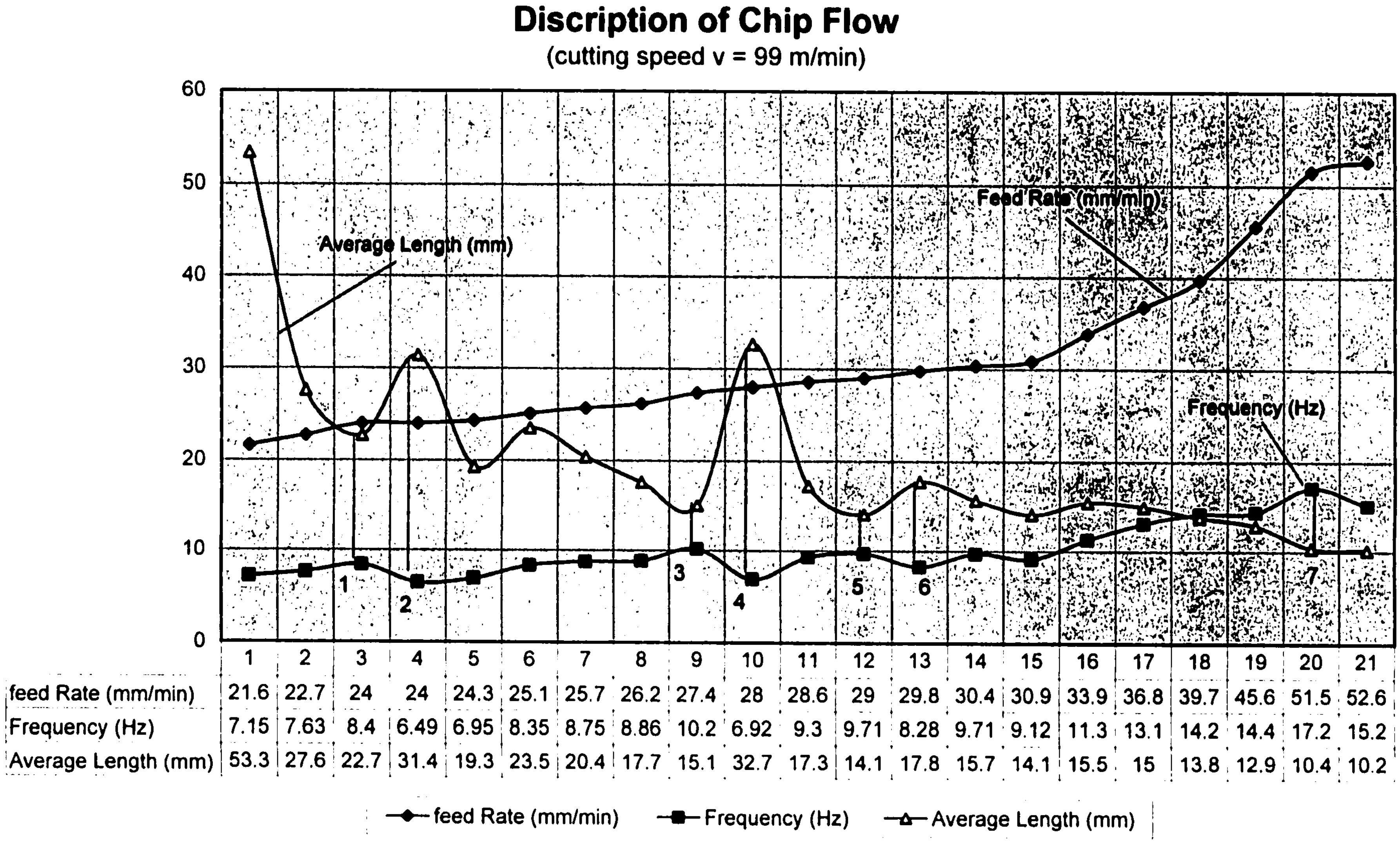
4.2 Analysis of Experimental Result

The relationship between frequencies of chips flow and chips length should be found from the analysis of experiment results. The chips' samples were randomly taken from each drilling, and they were counted and measured for the analysis. All the data on chip size acquired from experiments has been listed in **Appendix 3**. The average length of chips from each drilling can be obtained from the measurements and calculation. All data from the experiment of group one (cutting speed v = 99 m/min) is listed in the **Table 4-5**, and its description of chart curve is given in the **Figure 4-11** to revealing the relationship between chips length and frequencies. The data includes the feed rate used in the experiment, the total mean of frequencies from sensor signals and calculations, and the average length of chips from measurements and calculations.

In **Figure 4-11** the feed rates are increased from 21.6 mm/min up to 52.6 mm/min. Generally, as expected, the increase in feed rates resulted in increased frequencies and decreased the average length of chips. The frequency varies down or up at some points because of some uncertain reasons. The interesting thing is that the average length undergoes corresponding variation at these points. Seven points can be found in the diagram obviously. At point 1, 3, and 5, the frequencies are at convex points, but the average lengths are at concave point. Oppositely at point 2, 4, 6, and 7, the frequencies are at concave points, but the average lengths are at convex point. These points show more clearly the frequency of chips flow has corresponding variations when the chips are at different lengths.

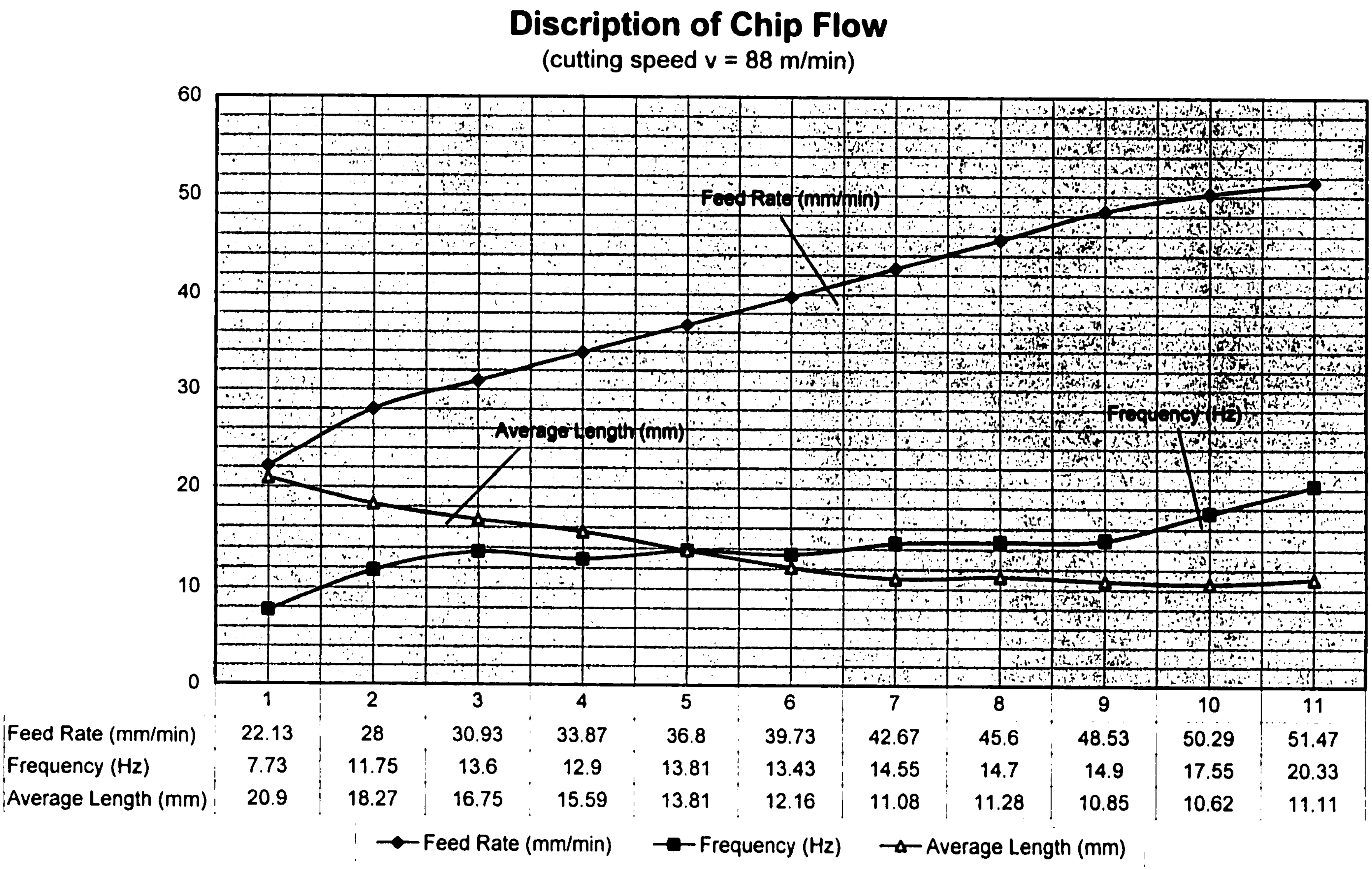
Table 4-5 The Data from group one (v = 99 m/min)

Feed Rate (mm/min)	Total Mean of Frequency (Hz)	Average Length (mm)
21.55	7.15493	53.25
22.72	7.632353	27.6
23.96	8.396825	22.66
23.96	6.492	31.39
24.28	6.95122	19.26
25.13	8.354839	23.52
25.65	8.745763	20.44
26.24	8.859649	17.67
27.44	10.232	15.14
28	6.923	32.67
28.59	9.296	17.29
29.04	9.712	14.07
29.76	8.27778	17.8
30.35	9.714286	15.74
30.93	9.122449	14.06
33.87	11.26667	15.53
36.8	13.12195	15
39.73	14.21053	13.75
45.6	14.3871	12.93
51.47	17.2069	10.4
52.64	15.19	10.2



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
feed Rate (mm/min)	21.6	22.7	24	24	24.3	25.1	25.7	26.2	27.4	28	28.6	29	29.8	30.4	30.9	33.9	36.8	39.7	45.6	51.5	52.6
Frequency (Hz)	7.15	7.63	8.4	6.49	6.95	8.35	8.75	8.86	10.2	6.92	9.3	9.71	8.28	9.71	9.12	11.3	13.1	14.2	14.4	17.2	15.2
Average Length (mm)	53.3	27.6	22.7	31.4	19.3	23.5	20.4	17.7	15.1	32.7	17.3	14.1	17.8	15.7	14.1	15.5	15	13.8	12.9	10.4	10.2

Figure 4-11 Discription of chip flow (cutting speed v = 99 m/min)



	1	2	3	4	5	6	7	8	9	10	11
Feed Rate (mm/min)	22.13	28	30.93	33.87	36.8	39.73	42.67	45.6	48.53	50.29	51.47
Frequency (Hz)	7.73	11.75	13.6	12.9	13.81	13.43	14.55	14.7	14.9	17.55	20.33
Average Length (mm)	20.9	18.27	16.75	15.59	13.81	12.16	11.08	11.28	10.85	10.62	11.11

Figure 4-12 Discription of chip flow (cutting speed v = 88 m/min)

Figure 4-12 shows also the relationship between chips length and frequencies from the experiment of group two (cutting speed v = 88 m/min). It looks more like in normal situation with more smooth curves.

In **Appendix 3,** comparing all charts and photos of chips we can find that when the total mean of frequencies are around 15 (Hz) the chips size are ideal or acceptable.

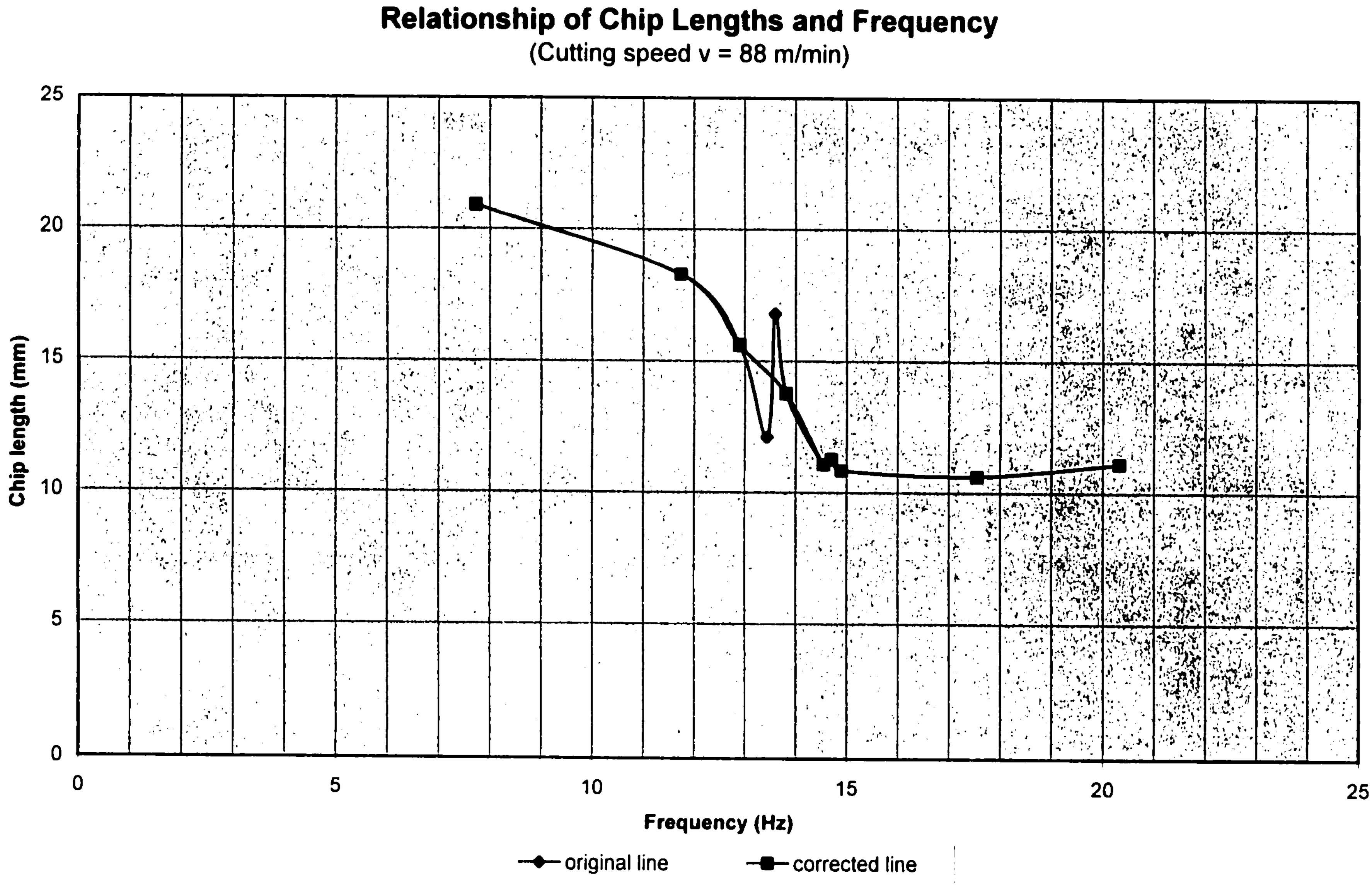


Figure 4-13 Relationship of Chip Length and Frequency (Cutting speed v = 88 m/min)

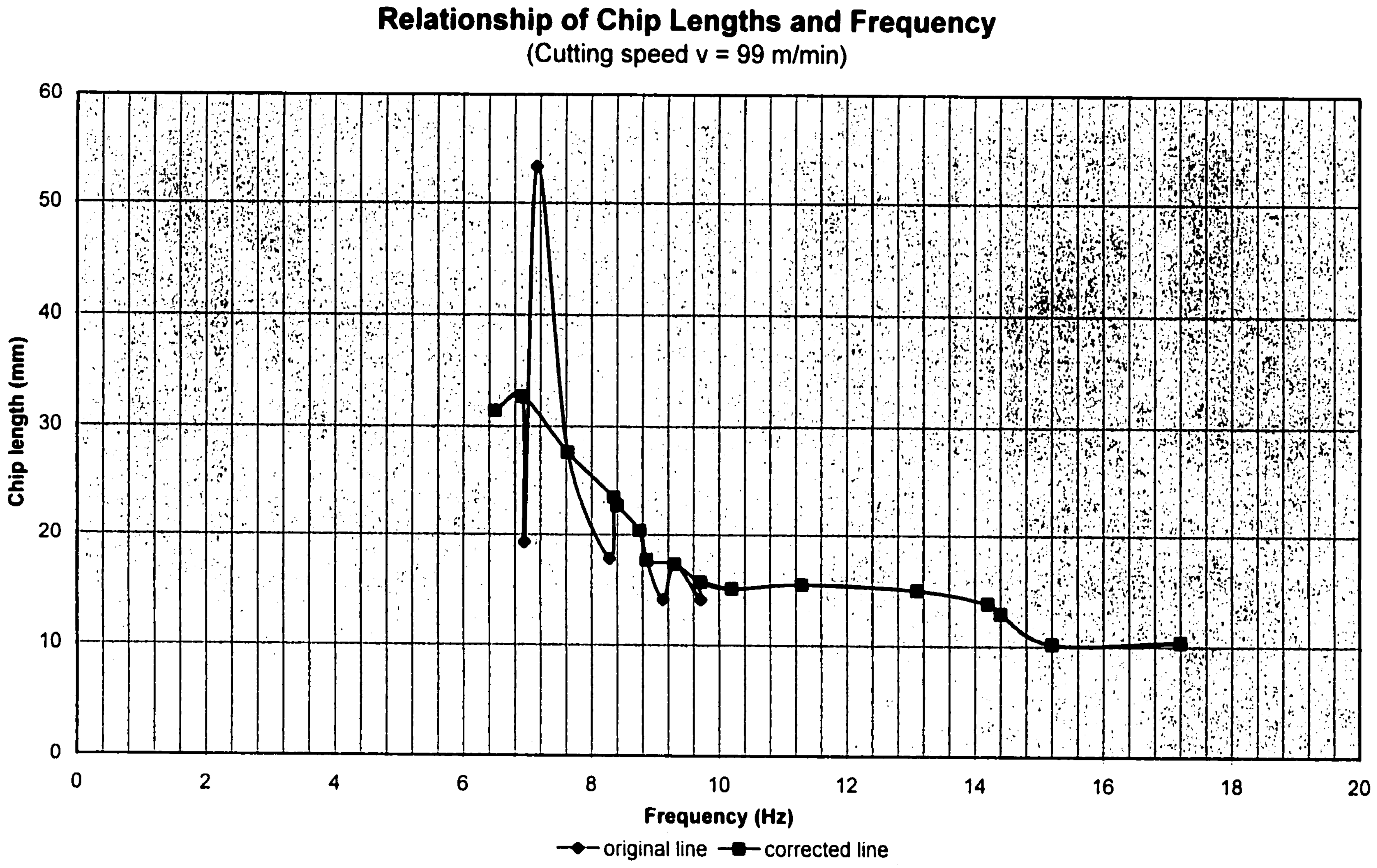


Figure 4-14 Relationship of Chip Length and Frequency (Cutting speed v = 99 m/min)

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The major objective of this thesis was to develop a reasonably reliable system for chip monitoring in deep-hole machining. Although there are several kinds of methods that can be used for chip status monitoring in deep-hole machining, the method selected in this investigation is believed to be a viable method. In the research, a monitoring system was designed according to the principle of manufacturing processes monitoring, and the characteristics of deep-hole machining process. As a manufacturing process monitoring system, one selected and experimentally investigated in this research contains three basic phases: sensing, signal processing, and classification (decision making). An inductive proximity sensor was selected for data acquisition (sensing), the sensing location and layout have been selected, designed and built and a personal computer set-up assembled for data signal processing. Throughout the investigation the suitability of the monitoring method for an expert system control of deep-hole machining process has been a principal concern.

From the analysis of the experimental result, it has been shown that the inductive proximity sensor is a suitable sensor for chip status monitoring in deep-hole machining. Sensor signal processing is aimed at obtaining monitoring indices that describe the characteristic features of chip size and is critical to the success of the monitoring. With the inductive proximity sensor, three monitoring indexes (frequencies) are selected through the analysis of sensor signals, and they obviously correspond to monitoring conditions (chip size). The decision-making is based on the relationship between the process conditions (chip size) and monitoring indices (frequencies). This relationship can be described in a number of ways such as patterns, fuzzy systems, decision trees, expert systems, and neural networks. It has been proven by previously conducted research that the expert system is a suitable control system with several advantages in deep-hole machining, and is capable of performing a real-time control along with sequence control and safety monitoring. Because of the choice of the expert control for deep-hole machining process the chip size monitoring system developed in this research has been proven an adequate solution.

The deep-hole machining process is believed a complex and uncertain process in a narrow domain, and expert system offers the best solution for a such process. In addition, because of the uncertainties it seems impossible to have complete initial information for the monitoring, therefore, it is necessary to continuously update the knowledge at any stage of the system development and operating, and expert system can provide those functions since it is capable of adaptive learning. By combining the decision trees (learning from experiment samples), analytical studies (physical law of the process) and empirical knowledge of the experts and operators, expert system can be very effective and efficient methods, for monitoring of deep-hole machining processes.

It is believed that In the learning phase of the expert system, the relationship between chip size and the sensor signal has been established based on the experimental results. This means that the frequencies of chip flow can be used successfully as the information regarding the chip size. The inductive proximity sensor can fulfil the function very reliably.

The new monitoring system of chip size in deep-hole machining process is very important stage of total expert system and monitoring indexes (frequencies) defined in this investigation are proven to be correct information of chip size. The inductive proximity sensor has provided a strong signal about chip concentration. The experimental tests have confirmed its reliability beyond any doubts. It is suggested that similar system may be suitable for some other machining operations where the visual observation of chip formation is obstructed by shields and covers.

5.2 Recommendations for future work

The relationship between the frequencies of chip flow and the chip size should be combined with domain knowledge. More experiments and knowledge are needed to build the complete knowledge base for expert system, and to find the exact relationship of frequencies and chips size. In addition, the monitoring systems with multiple sensors are necessary for expert system to make more accurate decision in machine tool control. It is not infeasible to used cutting force sensors and vibration (chatter) signals sensors for purpose of expert control during deep-hole machining. With the multiple sensors one must make sure that the conflicting decisions are resolved by setting priority sequence of control actions.

Reference:

1. Perdur S. Subramanya, "Expert Control of Deep Hole Machining System: An Artificial Intelligence Technique for Real Time Control of Deep Hole Machining Process". Thesis (Ph.D.)—Deptpartment of Mechanical Engineering, Concordia University, Montreal, Canada, 1994.
2. Steve F. Krar, Mario Rapisarda, Albert F. Check, "Machine Tool and Manufacturing Technology", 1998.
3. M.O.M. Osman, "The BTA Technique - Fast Hole Machining". Tooling & Production Magazine, April 1975.
4. Ahttp://www.americanheller.com/.
5. M.O.M. Osman, V. Latinovic, "On the Development of Multi-Edge Cutting Tools for BTA Deep-Hole Machining". Journal of Engineering for Industry, V0l. 98, No. 2, May 1976.
6. V. Latinovic, M.O.M. Osman (1989), "Optimal Design of BTA Deep-Hole Cutting Tools With Staggered Cutters", Journal of Production Research, Vol. 27, No. 1, 1989.
7. B.J. Griffiths (1982), "An Investigation into the Role of the Burnishing Pads in the Deep Hole Machining Process", Ph.D., Thesis, Department of Production Technology, Brunel University, UK, 1982.

8. R.J. Syrett, H.J. Bult, "The Relative Performance of Cutting Fluids in Deep Hole Drilling" The proceeding of the Third International Conference on Deep Hole Drilling and Boring, Brunel University, May 1979.
9. G. Zwingmann, "Cutting Oils for Deep Hole Boring" International Conference on Deep Hole Drilling and Boring, Brunel University, May 1975.
10. V.P. Astakhov, M.O.M. Osman, V. Latinovic, "Principles of Semiotic On-Line Control for Deep-Hole Machining System", 1999.
11. Joseph Giarratano & Gary Riley, "Expert Systems: Principles and Programming". PWS Publishing, Boston, 1998
12. D.M. O'Neill, P.W. Mullarkey, "A Knowledge-Based Approach to Real Time Signal Monitoring", 1988.
13. Garry Marshall, "Students' Guide to Expert Systems". Heinemann Newnes, 1990
14. Adedeji B. Badiru, "Expert Systems: Applications in Engineering and Manufacturing", Prentice Hall, Englewood Cliffs, N.J,.1992.
15. R. Du, M.A. Elbestawi, S.M. Wu, "Automated Monitoring of Manufacturing Process, Part 1", Journal of Engineering for Industry, Vol. 117/121, May 1995.

16. R. Du, M.A. Elbestawi, S.M. Wu, "Automated Monitoring of Manufacturing Process, Part 2", Journal of Engineering for Industry, Vol. 117/133, May 1995.

17. Harry N. Norton, "Sensor and Analyzer Handbook", Prentice-Hall, Englewood Cliffs, NJ, 1982.

18. Jih-Hua Chin, Jang-Shyong Wu, Rouh-Song Young, "The Computer Simulation and Experimental Analysis of Chip Monitoring for Deep Hole Drilling", Journal of Engineering for Industry, Vol. 115/185, May 1993.

19. I.S. Jawahir, C.A. van Luttervelt, "Recent Development in Chip Control Research and Applications", Annals of the CIRP Vol. 42/2/1993.

20. Ljubomir S. Lukic (1987), "Contribution to Development of High Removal Rate Systems for Deep-Hole Drilling with AC Control",.Produktivnost Vol.2, No. 3, 1987 (in Serbian).

21. Cutler Hammer (1999), "Sensors Product Guide".

22. Arnold H. Vandoren, "Data Acquisition Systems", Reston, Va., Reston Pub. Co., 1982.

23. National Instruments (2000), "DAQ Fundamentals".

24. D.V. Gadre (1998), "Programming the Parallel Port – Interfacing the PC for Data Acquisition and Process Control", Lawrence, KS, R&D Books, 1998.

25. J. C. Willems , "From Time Series to Linear Systems", Automatica, Vol. 22, No.5, 1986.

26. S. M. Wu (1977), "Dynamic Data System - A New Modeling Technique", Journal of Engineering for Industry, Vol. 99, 1977

27. S. M. Kay, "Modern Spectral Estimation, Theory and Applications", Prentice Hall, 1988.

28. J. Tlusty and F. Ismail, "Basic Non-Linearity in Machining Chatter", Annals of CIRP, Vol.30, 1981.

29. Y. Yan and T. Shimogo, "New Indices in the Sequence Domain and Their Application to Condition Monitoring of Mechanical System", Mechanical Systems & Signal Processing, Vol. 4, No. 4, 1990.

30. R. H. Lyon, "Machinery Noise and Diagnostics", Butterworths Publishers, 1987.

31. C. Cempel, "Limit Value in the Practice of Machine Vibration Diagnostics", Mechanical Systems & Signal Processing, Vol. 4, No. 6, 1990.

32. R. Du, J. M. Tarajos, and B. K. Gawlik, "A New Strategy for Preventive Monitoring with an Application in Tool Wear Monitoring in Turning Using Cutting Forces", The proceeding of the 5th International Conference on Production Engineering, Design & Control, Alexandria, Egypt, Dec. 1992.

33. R. Du and S. M. Wu, "Alarm Threshold Estimation for On-Line Monitoring of Machining Processes", Proc. of Manufacturing International'90, Vol. 5, 1990.

34. L. Pau, "Knowledge Representation Approaches in Sensor Fusion", Automatica, Vol.25, No.2, 1989.

35. A. M. Agogino, S. Srinivas, and K. M. Schneider, "Multiple Sensor Expert System for Diagnostic Reasoning, Monitoring and Control of Mechanical Systems", Mechanical Systems and Signal Processing, Vol. 2, 1988.

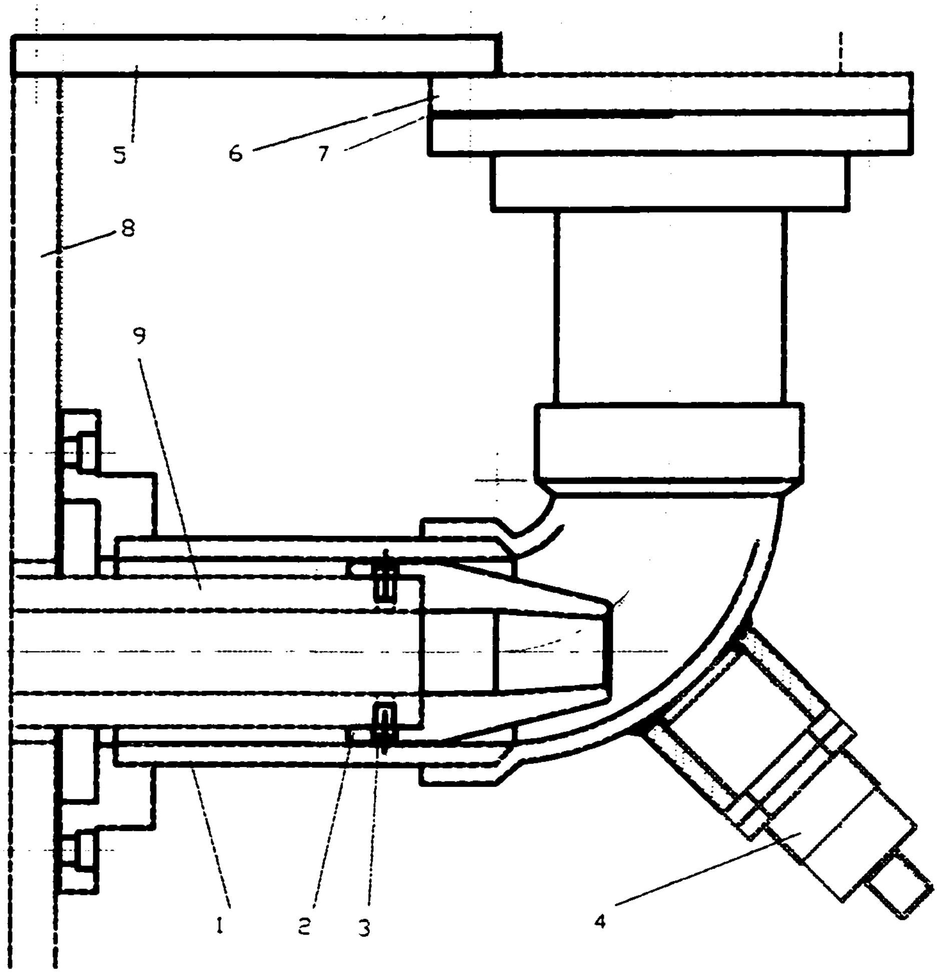
36. J. L. Andreasen, L. De Chiffre, "Automatic Chip-Breaking Detection in Turning by Frequency Analisis of Cutting Force", Annals of the CIRP, Vol. 42/1/, 1993.

37. W. Grzesik, P. Bernat, "An Investigation of the Cutting Process for Chip Breaking Monitoring in Turning of Steel", Journal of Manufacturing Science and Engineering, Vol. 120/555, 1998.

Appendix 1

The mechanical design for chip size monitoring system

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



NO.	DESCRIPTION	QUANTITY	METERIAL
9	FRONT OF DISCHARGE CHANNEL	1	—
8	TOOL DRIVING BOX	1	—

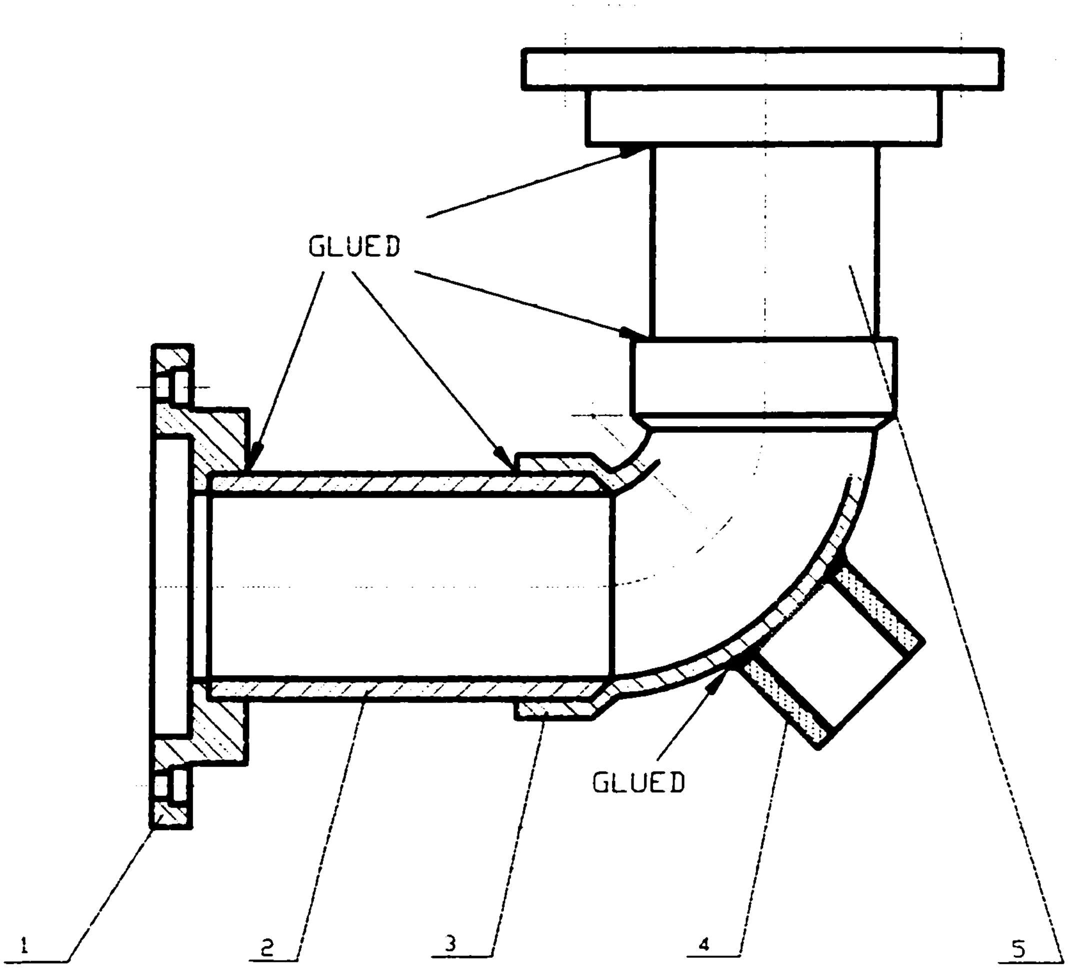
NO.	DESCRIPTION	QUANTITY	METERIAL
7	WASHER	2	—
6	END OF DISCHARGE CHANNEL	1	—
5	CONNECT BAR	2	44W
4	INDUCTIVE PROXIMITY SENSOR	1	E57-30LE22-CD
3	DESCRIPTION	2	METERIAL
2	SPRAY HEAD	1	ASSEMBLY-2
1	BEND OF DISCHARGE CHANNEL	1	ASSEMBLY-1

MECHANICAL DESIGN OF SENSOR HOLDER MOUNT

SIZE	FSCM NO.	DWG NO.	REV
A		ASSEMBLY	0
SCALE 1:2		SHEET 1/1	

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED



5	CHANNEL 2	QUANTITY	ASSEMBLY-1-5
4	SCREW SLEEVE	1	ASSEMBLY-1-4
3	BEND	2	METERIAL
2	CHANNEL 1	1	ASSEMBLY-1-2
1	FLANGE	1	ASSEMBLY-1-1
NO.	DESCRIPTION	QUANTITY	METERIAL

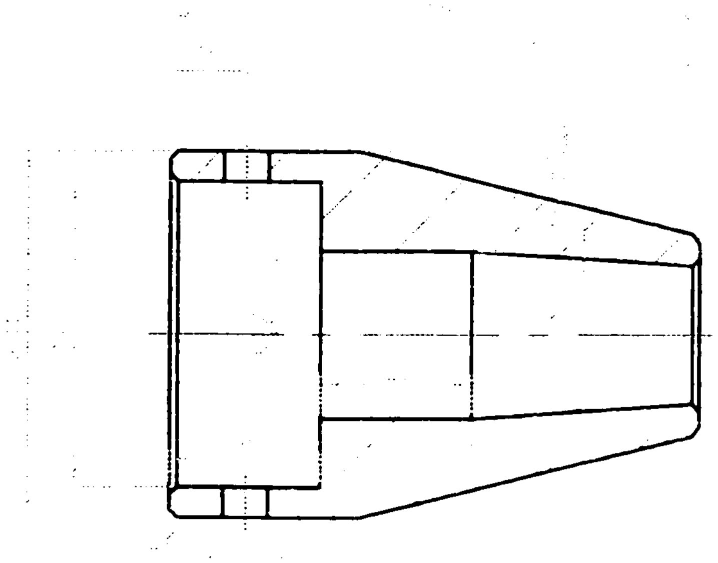
BEND OF DISCHARGE CHANNEL

SIZE	FSCM NO.	DWG NO.	REV
A		ASSEMBLY-1	0

SCALE 1:2

SHEET 1/1

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



NOTE: 1. MAT-
2. ALL CHAMFER: 45°x1.5

SPRAY HEAD

SIZE A	FSCM NO.	DWG NO. 2	REV 0
SCALE 1:1		SHEET 1/1	

Appendix 2

The C program for data acquisition in chip size monitoring

```
/**************************************************/
/*   File Name chips.c                            */
/*                                                */
/*   Function:Input a logic siganl from           */
/*            "ready" bit of printer port         */
/*             and find its frequency.            */
/**************************************************/
#include <dos.h>
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <process.h>
#include <string.h>
#include <math.h>
#include <time.h>

#define PSTUS 0x379

void interrupt (*old_time)(void);
void interrupt rtime();
void get_key(char *key_flag, char *key_value);

FILE *stream;
char frequency[10];
char timebuffer[10];
int freq,lowflag,saveflag;
```

```
 int Count,Index,Set;
 union REGS regs;
 time_t ltime;

 void Rtime_Set(void)
  {
  disable();/*for time index*/
  /* clock control word*/
  /*d7,d6: channel selection*/
  /*d5,d4: read and write*/
  /*d3,d2,d1: working mode 0 to 5 */
  /* d0: binary or BCD; d0=0 binary */
  outportb(0x43,0xb6);/*clock interrupt word*/
  outportb(0x40,0x0b);/*50ms interrupt one time*/
  outportb(0x40,0xe9);
  enable();
  old_time=getvect(0x1c);
  setvect(0x1c,rtime);
  }

void Time_Initial(void)
{
  Count=0;
  Index=0;
  Set=20;
}

void Time_Off(void)
{
 disable();
 outp(0x43,0xb6);
```

```
  outp(0x40,0x00);
  outp(0x40,0x00);
  setvect(0x1c,old_time);
  enable();
 }

main()
{
     char key_value, key_flag;
     unsigned int flag1;
     int i,j,k;
     float temp,temp1;
     char yesno, filename[15];

     Rtime_Set();
     Time_Initial();

loop0:    printf("           Please type a data file name \n\n");
     scanf("%13s",filename);
     if((stream=fopen(filename,"r"))!=NULL)
     {
       printf("       The file alreade exist, overwrite it?
(Yes/No) \n\n");
       scanf("%c%c",&yesno,&yesno);
       fclose(stream);
       if((yesno!='Y') && (yesno!='y')) goto loop0;
     }
     stream=fopen(filename,"w");
     if(stream==NULL)  printf("The file data was not opened\n");
     time (&ltime);
     printf("The begining time is %s\n", ctime(&ltime));
     fprintf(stream,"The begining time is %s\n", ctime(&ltime));
```

```
     lowflag = 0;
     freq = 0;
loop1: /* freq+=1;   */
      if(Index==0)
      {
     if(inportb(PSTUS)&0x80)
     {
       for(i=0;i<20;i++);
       if(inportb(PSTUS)&0x80)
       {
         if(lowflag==0)
         {
           lowflag = 1;
           freq += 1;
         }
       }
     }
     if(!(inportb(PSTUS)&0x80))
     {
       for(i=0;i<20;i++);
       if(!(inportb(PSTUS)&0x80))
       {
         lowflag = 0;
       }
     }
      }
     /* waiting for key "ESC" to stop the program */
     get_key(&key_flag, &key_value);
     flag1=key_flag&0x40;
     if(flag1==0)
     {
```

```
      regs.h.ah=0;
      int86(0x16,&regs,&regs);
      if(key_value==0x1b)
      {
         time (&ltime);
         printf(" \nThe end time is %s\n", ctime(&ltime));
         if(stream!=NULL)  fprintf(stream,"\nThe end time is %s\n",
            ctime(&ltime));
         if(stream==NULL)  printf("The file data was not
renewed!!!\n");
         else  fclose(stream);
         Time_Off();
         disable();
         abort();
       }
       }
       if(Index&&saveflag)
       {
      saveflag = 0;
      _strtime(timebuffer);
      timebuffer[9]=timebuffer[8];
      timebuffer[8]=',';
      fputs(timebuffer,stream);
      itoa(freq,frequency,10);
      fputs(frequency,stream);
      fputs("\n",stream);
      printf("%s%s\n",timebuffer,frequency);
      freq = 0;
       }
      goto loop1;

}
```

```
void get_key(char *key_flag, char *key_value)
     {
     regs.h.ah=1;
     int86(0x16,&regs,&regs);
     *key_flag=regs.x.flags;
     *key_value=regs.h.al;
     }

void interrupt rtime()     /*real time interrupt*/
{
    Count++;
    if(Count>=Set)
    {
      Count=0;
      if(Index) {Index=0; saveflag=1;}
      else {Index=1;}
    }
    (*old_time)();
}
```

Appendix 3

Photos, data, and graphics regarding chips from experiments

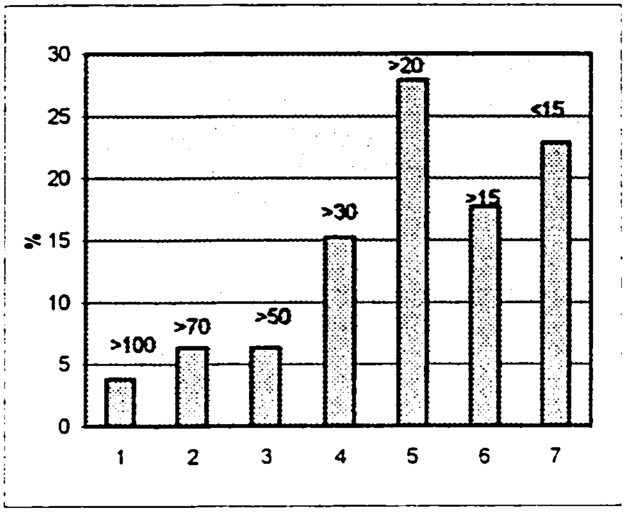
Cutting speed v = 99 m/min, Feed rate f = 22.72 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	4	4	4	
2	5	9	4.5	
3	8	17	5.666666667	
4	7	24	6	
5	7	31	6.2	6.2
6	5	36	6	6.4
7	7	43	6.142857143	6.8
8	9	52	6.5	7
9	8	60	6.666666667	7.2
10	7	67	6.7	7.2
11	8	75	6.818181818	7.8
12	8	83	6.916666667	8
13	8	91	7	7.8
14	9	100	7.142857143	8
15	7	107	7.133333333	8
16	7	114	7.125	7.8
17	6	120	7.058823529	7.4
18	8	128	7.111111111	7.4
19	7	135	7.105263158	7
20	8	143	7.15	7.2
21	8	151	7.19047619	7.4
22	5	156	7.090909091	7.2
23	5	161	7	6.6
24	9	170	7.083333333	7
25	4	174	6.96	6.2
26	7	181	6.961538462	6
27	8	189	7	6.6
28	3	192	6.857142857	6.2
29	6	198	6.827586207	5.6
30	6	204	6.8	6
31	6	210	6.774193548	5.8
32	9	219	6.84375	6
33	1	220	6.666666667	5.6
34	12	232	6.823529412	6.8
35	6	238	6.8	6.8
36	8	246	6.833333333	7.2
37	11	257	6.945945946	7.6
38	9	266	7	9.2
39	8	274	7.025641026	8.4
40	10	284	7.1	9.2
41	7	291	7.097560976	9
42	11	302	7.19047619	9
43	11	313	7.279069767	9.4
44	9	322	7.318181818	9.6
45	7	329	7.311111111	9
46	5	334	7.260869565	8.6
47	8	342	7.276595745	8
48	9	351	7.3125	7.6

Chips' length distribution

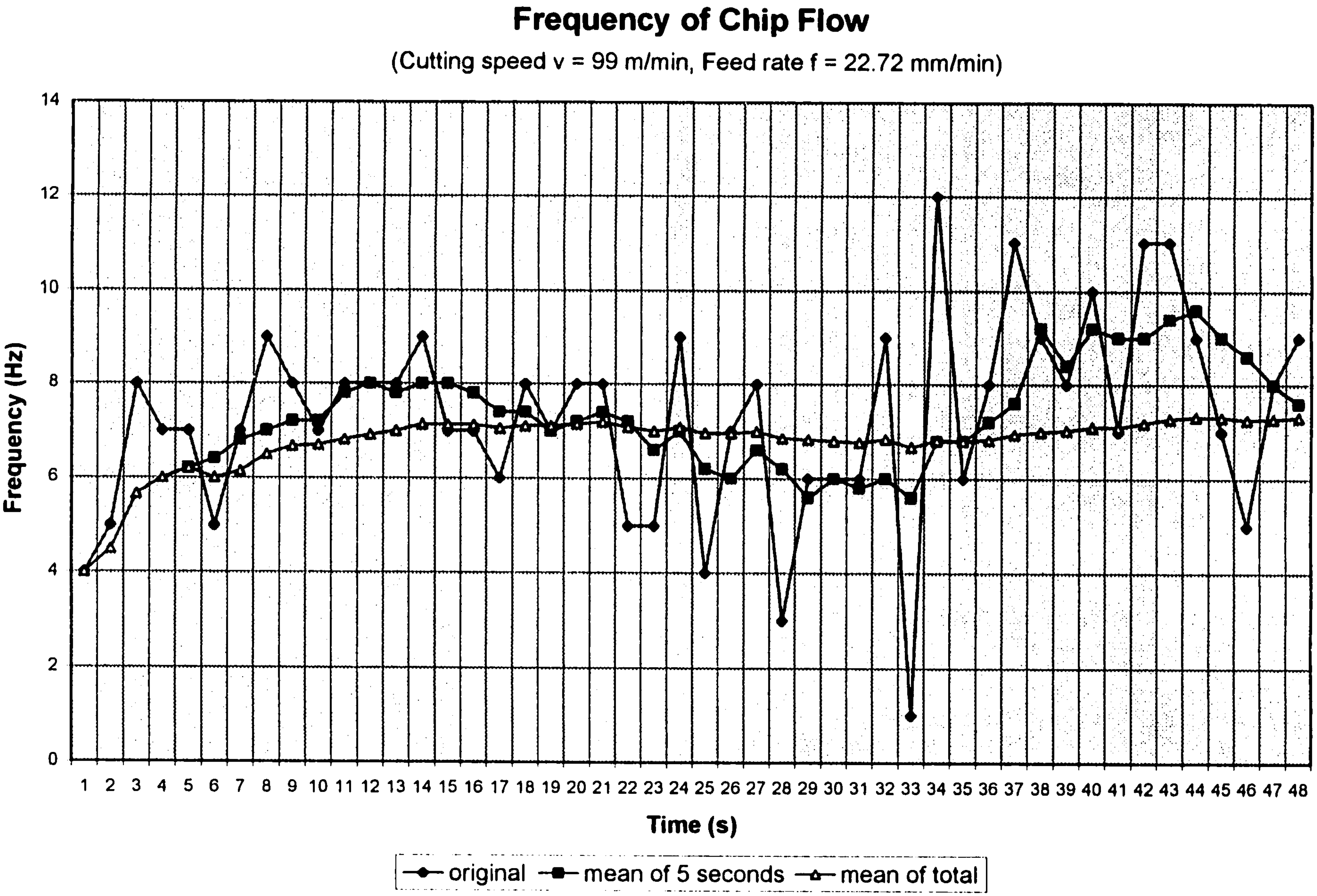
Chips' length (mm)	%
>100	3.8
>70	6.3
>50	6.3
>30	15.2
>20	27.9
>15	17.7
<15	22.8

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 7.31 Hz
2. Average length : 27.6 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 22.72 mm/min)
Frequency (Hz)
0
2
4
6
8
10
12
14
Time (s)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
original
mean of 5 seconds
mean of total

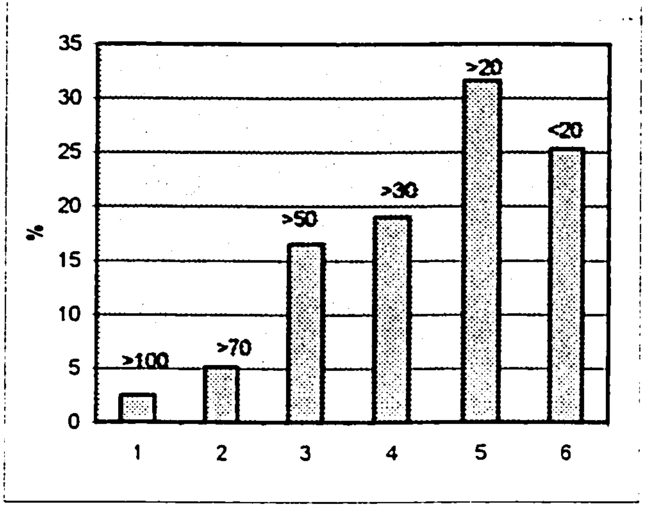
Cutting speed v = 99 m/min, Feed rate f = 23.96 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	11	11	11	
2	5	16	8	
3	5	21	7	
4	4	25	6.25	
5	1	26	5.2	5.2
6	5	31	5.166666667	4
7	4	35	5	3.8
8	7	42	5.25	4.2
9	4	46	5.111111111	4.2
10	6	52	5.2	5.2
11	4	56	5.090909091	5
12	7	63	5.25	5.6
13	4	67	5.153846154	5
14	8	75	5.357142857	5.8
15	6	81	5.4	5.8
16	4	85	5.3125	5.8
17	5	90	5.294117647	5.4
18	5	95	5.277777778	5.6
19	5	100	5.263157895	5
20	7	107	5.35	5.2
21	6	113	5.380952381	5.6
22	6	119	5.409090909	5.8
23	5	124	5.391304348	5.8
24	8	132	5.5	6.4
25	5	137	5.48	6
26	8	145	5.576923077	6.4
27	9	154	5.703703704	7
28	6	160	5.714285714	7.2
29	7	167	5.75862069	7
30	9	176	5.866666667	7.8
31	8	184	5.935483871	7.8
32	4	188	5.875	6.8
33	7	195	5.909090909	7
34	9	204	6	7.4
35	12	216	6.171428571	8
36	8	224	6.222222222	8
37	9	233	6.297297297	9
38	12	245	6.447368421	10
39	11	256	6.564102564	10.4
40	5	261	6.525	9
41	1	262	6.390243902	7.6
42	1	263	6.261904762	6
43	11	274	6.372093023	5.8
44	8	282	6.409090909	5.2
45	7	289	6.422222222	5.6
46	5	294	6.391304348	6.4
47	3	297	6.319148936	6.8
48	8	305	6.354166667	6.2

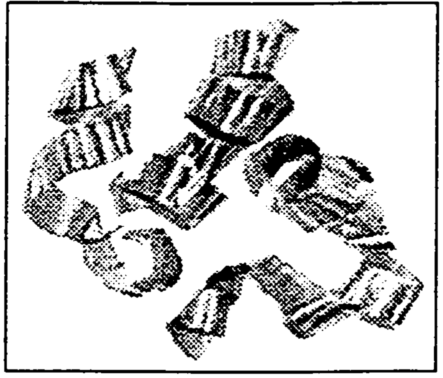
Chips' length distribution

Chips' length (mm)	%
>100	2.5
>70	5.1
>50	16.5
>30	19
>20	31.6
<20	25.3

Graphics of chips length distribution



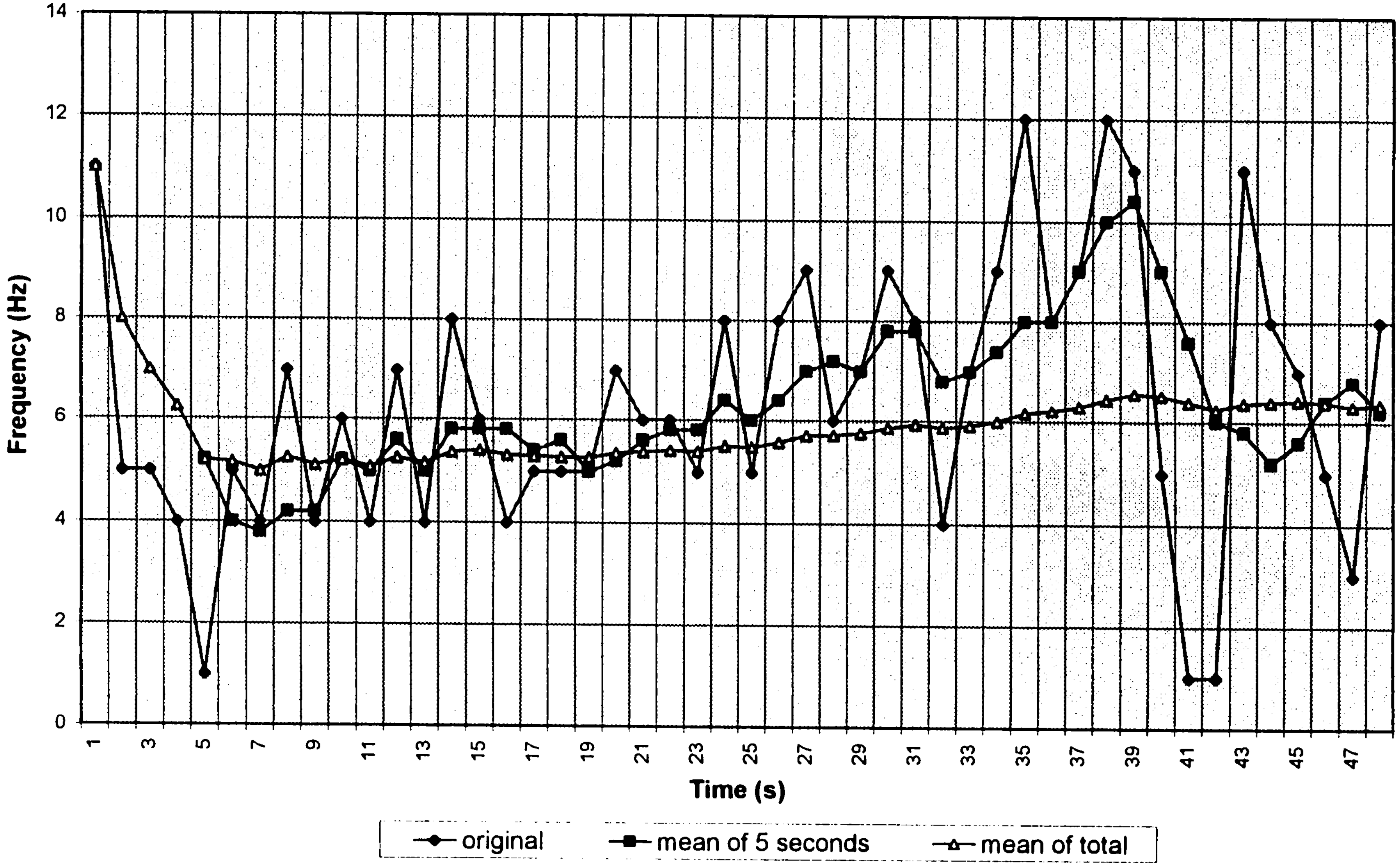
Sample of chips



1. Total mean of frequency: 6.35 Hz
2. Average length : 31.4 mm
3. Too many unacceptable
4. Unacceptbale

Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 23.96 mm/min)



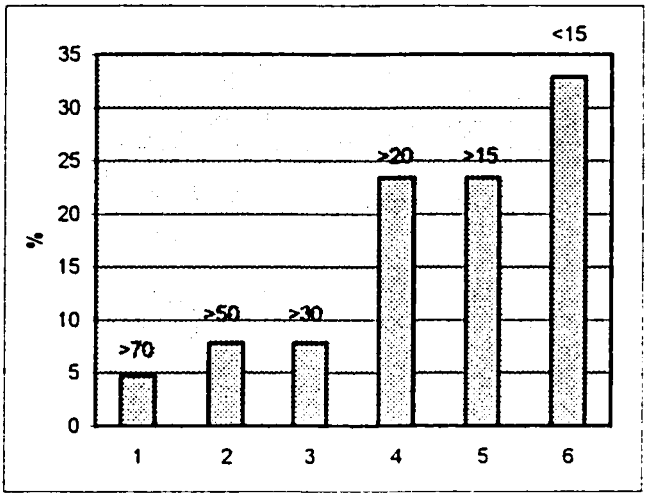
Cutting speed v = 99 m/min, Feed rate f = 23.96 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	7	7	7	
2	8	15	7.5	
3	10	25	8.333333333	
4	7	32	8	
5	9	41	8.2	8.2
6	8	49	8.166666667	8.4
7	8	57	8.142857143	8.4
8	7	64	8	7.8
9	7	71	7.888888889	7.8
10	8	79	7.9	7.6
11	10	89	8.090909091	8
12	8	97	8.083333333	8
13	8	105	8.076923077	8.2
14	8	113	8.071428571	8.4
15	7	120	8	8.2
16	9	129	8.0625	8
17	9	138	8.117647059	8.2
18	12	150	8.333333333	9
19	10	160	8.421052632	9.4
20	8	168	8.4	9.6
21	7	175	8.333333333	9.2
22	10	185	8.409090909	9.4
23	7	192	8.347826087	8.4
24	7	199	8.291666667	7.8
25	6	205	8.2	7.4
26	7	212	8.153846154	7.4
27	7	219	8.111111111	6.8
28	10	229	8.178571429	7.4
29	5	234	8.068965517	7
30	8	242	8.066666667	7.4
31	10	252	8.129032258	8
32	8	260	8.125	8.2
33	7	267	8.090909091	7.6
34	12	279	8.205882353	9
35	9	288	8.228571429	9.2
36	8	296	8.222222222	8.8
37	10	306	8.27027027	9.2
38	7	313	8.236842105	9.2
39	8	321	8.230769231	8.4
40	8	329	8.225	8.2
41	9	338	8.243902439	8.4
42	8	346	8.238095238	8
43	10	356	8.279069767	8.6
44	11	367	8.340909091	9.2
45	9	376	8.355555556	9.4
46	10	386	8.391304348	9.6
47	8	394	8.382978723	9.6
48	9	403	8.395833333	9.4

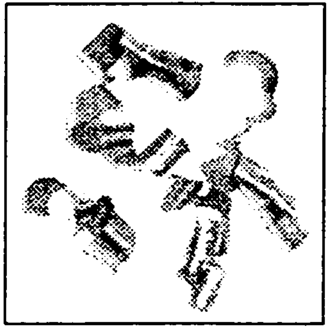
Chips' length distribution

Chips' length (mm)	%
>70	4.7
>50	7.8
>30	7.8
>20	23.4
>15	23.4
<15	32.9

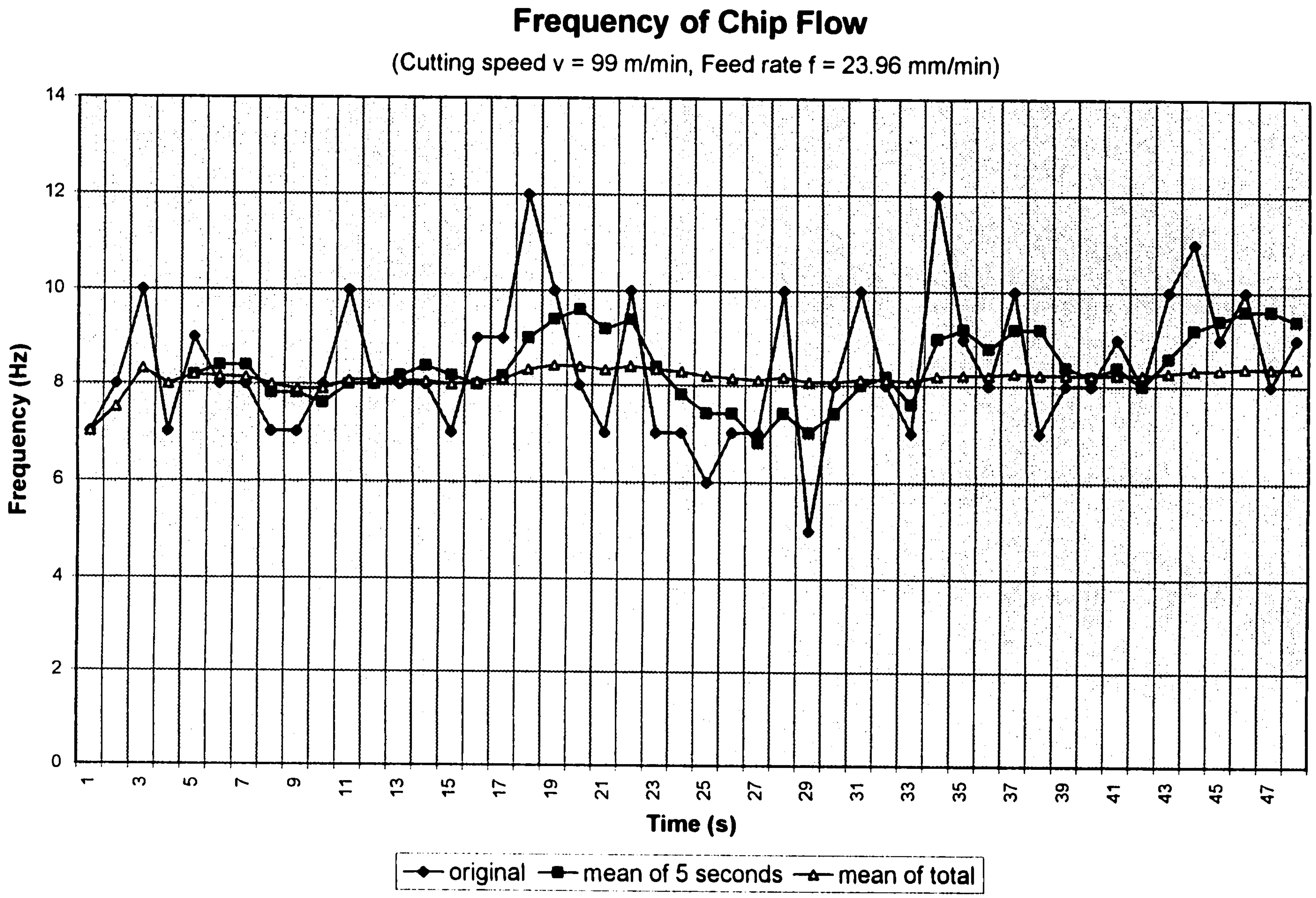
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 8.4 Hz
2. Average length : 22.7 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 23.96 mm/min)
Frequency (Hz)
14
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Time (s)
original
mean of 5 seconds
mean of total

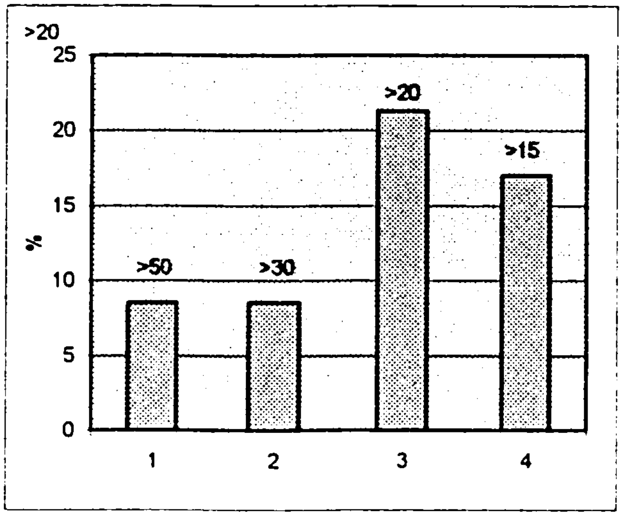
Cutting speed v = 99 m/min, Feed rate f = 24.28 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	5	5	5	
2	7	12	6	
3	8	20	6.666666667	
4	7	27	6.75	
5	4	31	6.2	6.2
6	6	37	6.166666667	6.4
7	6	43	6.142857143	6.2
8	8	51	6.375	6.2
9	4	55	6.111111111	5.6
10	7	62	6.2	6.2
11	4	66	6	5.8
12	3	69	5.75	5.2
13	8	77	5.923076923	5.2
14	6	83	5.928571429	5.6
15	8	91	6.066666667	5.8
16	9	100	6.25	6.8
17	6	106	6.235294118	7.4
18	8	114	6.333333333	7.4
19	4	118	6.210526316	7
20	6	124	6.2	6.6
21	6	130	6.19047619	6
22	7	137	6.227272727	6.2
23	8	145	6.304347826	6.2
24	8	153	6.375	7
25	8	161	6.44	7.4
26	8	169	6.5	7.8
27	13	182	6.740740741	9
28	8	190	6.785714286	9
29	7	197	6.793103448	8.8
30	7	204	6.8	8.6
31	7	211	6.806451613	8.4
32	7	218	6.8125	7.2
33	8	226	6.848484848	7.2
34	6	232	6.823529412	7
35	10	242	6.914285714	7.6
36	5	247	6.861111111	7.2
37	7	254	6.864864865	7.2
38	13	267	7.026315789	8.2
39	9	276	7.076923077	8.8
40	8	284	7.1	8.4

Chips' length distribution

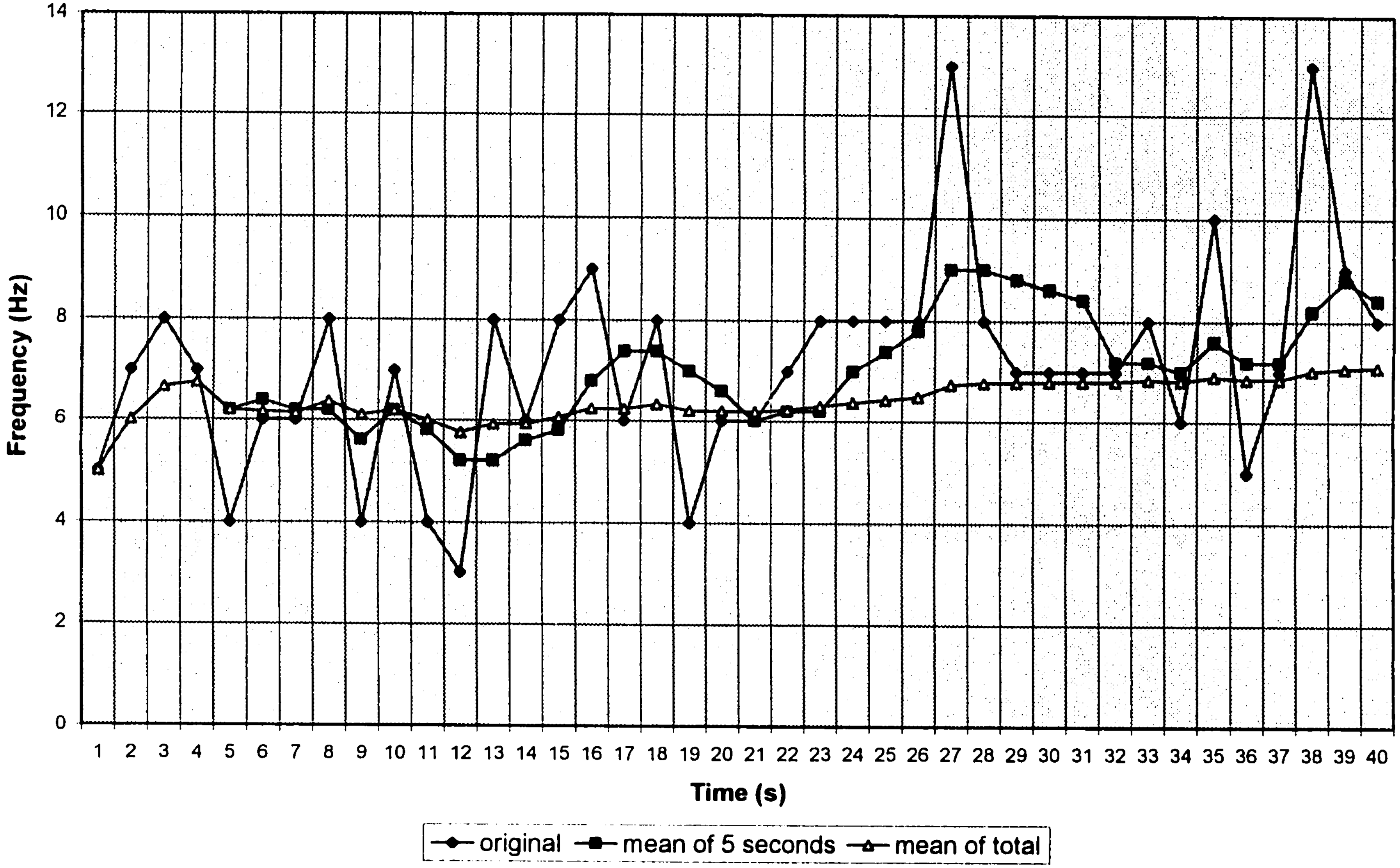
Chips' length (mm)	%
>50	8.5
>30	8.5
>20	21.3
>15	17

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 7.1 Hz
2. Average length : 19.3 mm
3. Too many unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 24.28 mm/min)

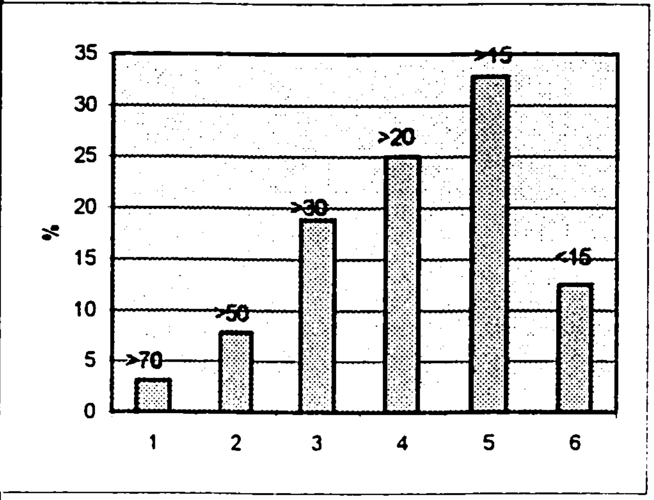
Cutting speed v = 99 m/min, Feed rate f = 25.13 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	8	8	8	
2	5	13	6.5	
3	8	21	7	
4	8	29	7.25	
5	9	38	7.6	7.6
6	9	47	7.833333333	7.8
7	9	56	8	8.6
8	12	68	8.5	9.4
9	8	76	8.444444444	9.4
10	6	82	8.2	8.8
11	7	89	8.090909091	8.4
12	9	98	8.166666667	8.4
13	11	109	8.384615385	8.2
14	9	118	8.428571429	8.4
15	13	131	8.733333333	9.8
16	10	141	8.8125	10.4
17	2	143	8.411764706	9
18	7	150	8.333333333	8.2
19	8	158	8.315789474	8
20	7	165	8.25	6.8
21	10	175	8.333333333	6.8
22	6	181	8.227272727	7.6
23	8	189	8.217391304	7.8
24	6	195	8.125	7.4
25	9	204	8.16	7.8
26	13	217	8.346153846	8.4
27	9	226	8.37037037	9
28	11	237	8.464285714	9.6
29	7	244	8.413793103	9.8
30	6	250	8.333333333	9.2
31	8	258	8.322580645	8.2
32	11	269	8.40625	8.6
33	9	278	8.424242424	8.2
34	9	287	8.441176471	8.6
35	5	292	8.342857143	8.4
36	9	301	8.361111111	8.6
37	7	308	8.324324324	7.8
38	10	318	8.368421053	8
39	1	319	8.179487179	6.4
40	7	326	8.15	6.8
41	9	335	8.170731707	6.8
42	10	345	8.214285714	7.4
43	12	357	8.302325581	7.8
44	6	363	8.25	8.8
45	8	371	8.244444444	9
46	7	378	8.217391304	8.6
47	9	387	8.234042553	8.4
48	8	395	8.229166667	7.6

Chips' length distribution

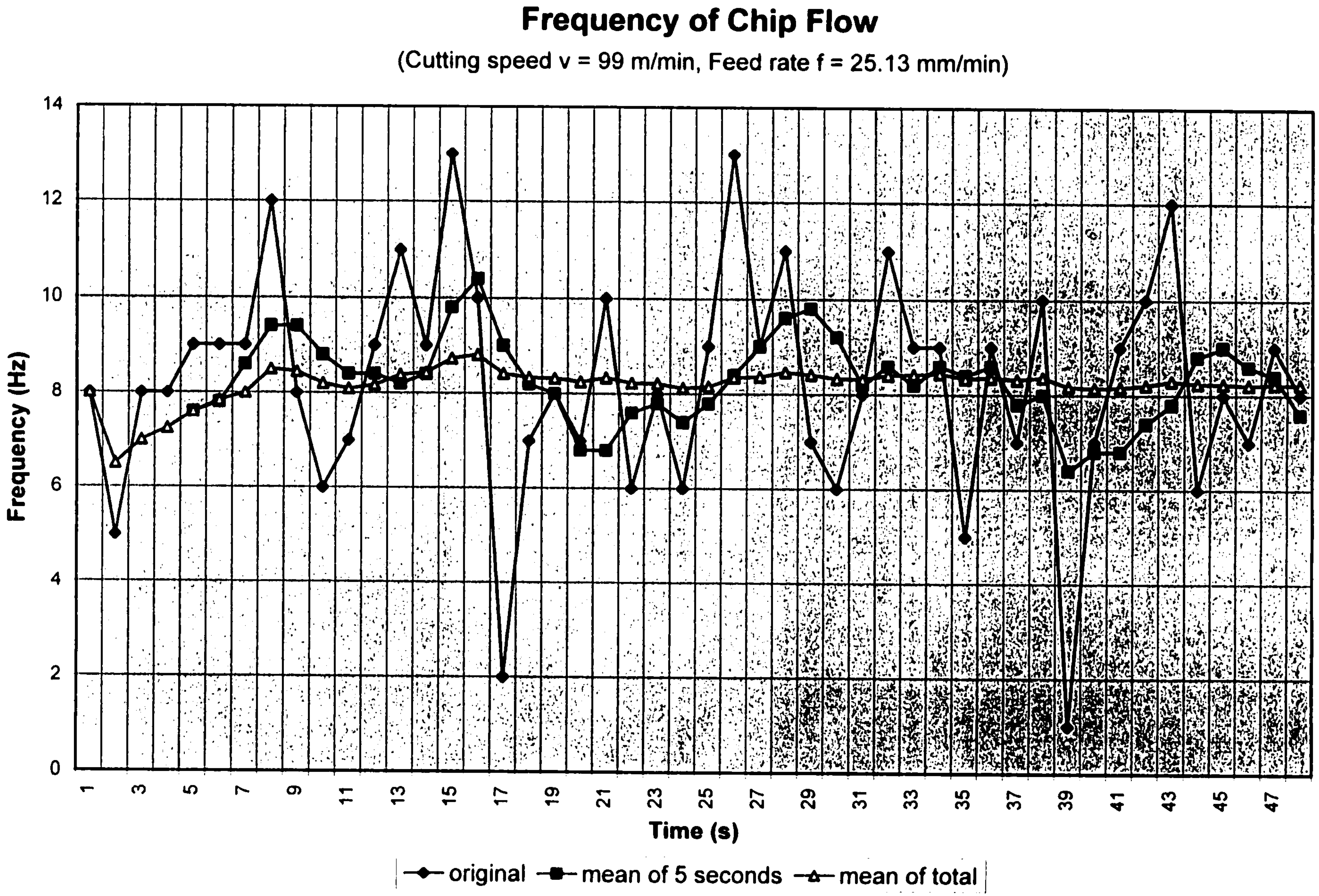
Chips' length (mm)	%
>70	3.1
>50	7.8
>30	18.8
>20	25
>15	32.8
<15	12.5

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 8.23 Hz
2. Average length : 23.5 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 25.13 mm/min)
Frequency (Hz)
14
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Time (s)
original
mean of 5 seconds
mean of total

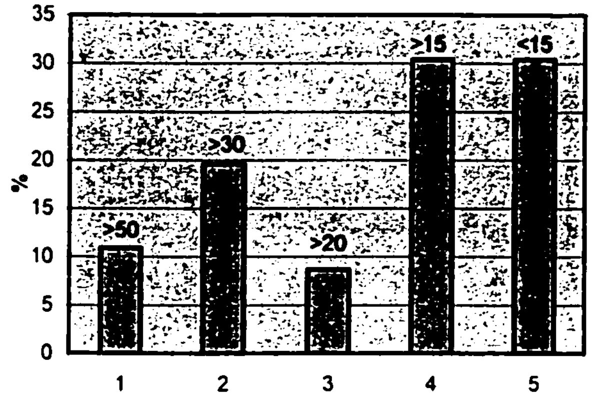
Cutting speed v = 99 m/min, Feed rate f = 25.65 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	8	8	8	
2	6	14	7	
3	13	27	9	
4	12	39	9.75	
5	11	50	10	10
6	10	60	10	10.4
7	7	67	9.571428571	10.6
8	7	74	9.25	9.4
9	10	84	9.333333333	9
10	9	93	9.3	8.6
11	6	99	9	7.8
12	5	104	8.666666667	7.4
13	7	111	8.538461538	7.4
14	10	121	8.642857143	7.4
15	10	131	8.733333333	7.6
16	9	140	8.75	8.2
17	9	149	8.764705882	9
18	8	157	8.722222222	9.2
19	8	165	8.684210526	8.8
20	9	174	8.7	8.6
21	14	188	8.952380952	9.6
22	11	199	9.045454545	10
23	11	210	9.130434783	10.6
24	11	221	9.208333333	11.2
25	10	231	9.24	11.4
26	13	244	9.384615385	11.2
27	13	257	9.518518519	11.6
28	11	268	9.571428571	11.6
29	7	275	9.482758621	10.8
30	9	284	9.466666667	10.6
31	8	292	9.419354839	9.6
32	7	299	9.34375	8.4
33	11	310	9.393939394	8.4
34	1	311	9.147058824	7.2
35	10	321	9.171428571	7.4
36	3	324	9	6.4
37	9	333	9	6.8
38	9	342	9	6.4
39	10	352	9.025641026	8.2
40	9	361	9.025	8
41	12	373	9.097560976	9.8
42	11	384	9.142857143	10.2
43	6	390	9.069767442	9.6
44	9	399	9.068181818	9.4
45	7	406	9.022222222	9
46	9	415	9.02173913	8.4
47	7	422	8.978723404	7.6
48	7	429	8.9375	7.8

Chips' length distribution

Chips' length (mm)	%
>50	10.9
>30	19.6
>20	8.7
>15	30.4
<15	30.4

Graphics of chips length distribution

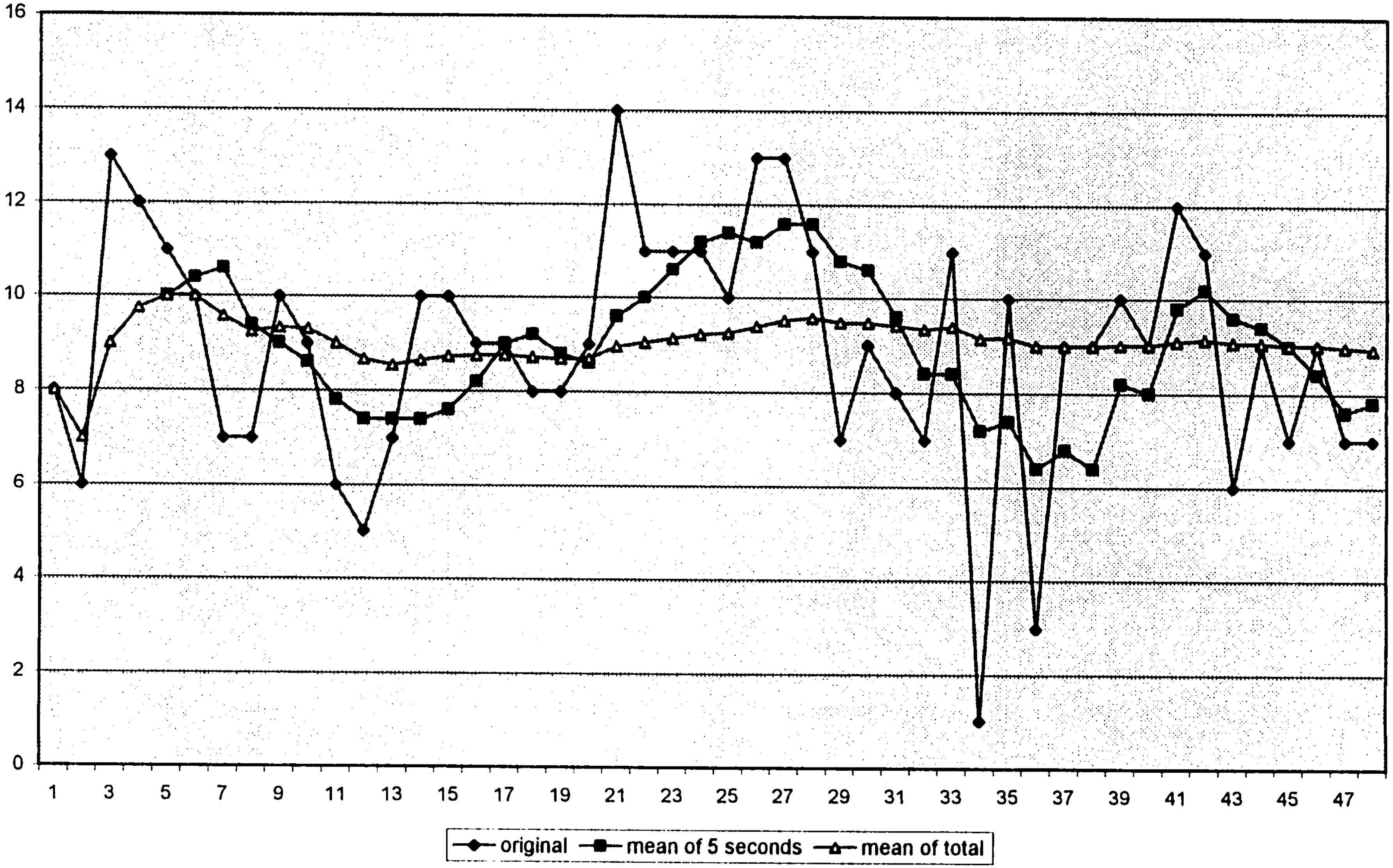


Sample of chips

1. Total mean of frequency: 8.94 Hz
2. Average length : 20.4 mm
3. Too many unacceptable
4. Unacceptbale

Frequency of Chips Flow

(Cutting speed v = 99 m/min, Feed rate f = 25.7 mm/min)



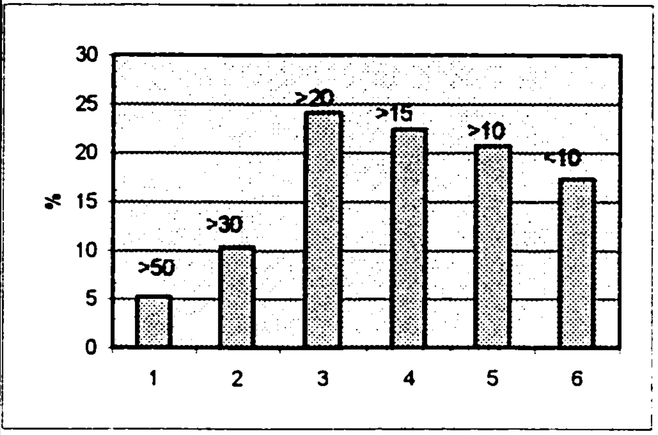
Cutting speed v = 99 m/min, Feed rate f = 26.24 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	15	15	15	
2	10	25	12.5	
3	10	35	11.66666667	
4	9	44	11	
5	9	53	10.6	10.6
6	14	67	11.16666667	10.4
7	5	72	10.28571429	9.4
8	10	82	10.25	9.4
9	14	96	10.66666667	10.4
10	10	106	10.6	10.6
11	9	115	10.45454545	9.6
12	10	125	10.41666667	10.6
13	7	132	10.15384615	10
14	1	133	9.5	7.4
15	6	139	9.266666667	6.6
16	10	149	9.3125	6.8
17	12	161	9.470588235	7.2
18	10	171	9.5	7.8
19	3	174	9.157894737	8.2
20	8	182	9.1	8.6
21	12	194	9.238095238	9
22	10	204	9.272727273	8.6
23	12	216	9.391304348	9
24	10	226	9.416666667	10.4
25	15	241	9.64	11.8
26	12	253	9.730769231	11.8
27	9	262	9.703703704	11.6
28	2	264	9.428571429	9.6
29	8	272	9.379310345	9.2
30	11	283	9.433333333	8.4
31	9	292	9.419354839	7.8
32	9	301	9.40625	7.8
33	8	309	9.363636364	9
34	7	316	9.294117647	8.8
35	9	325	9.285714286	8.4
36	7	332	9.222222222	8
37	8	340	9.189189189	7.8
38	12	352	9.263157895	8.6
39	9	361	9.256410256	9
40	1	362	9.05	7.4
41	10	372	9.073170732	8
42	6	378	9	7.6
43	11	389	9.046511628	7.4
44	11	400	9.090909091	7.8
45	8	408	9.066666667	9.2
46	5	413	8.97826087	8.2
47	9	422	8.978723404	8.8
48	11	433	9.020833333	8.8

Chips' length distribution

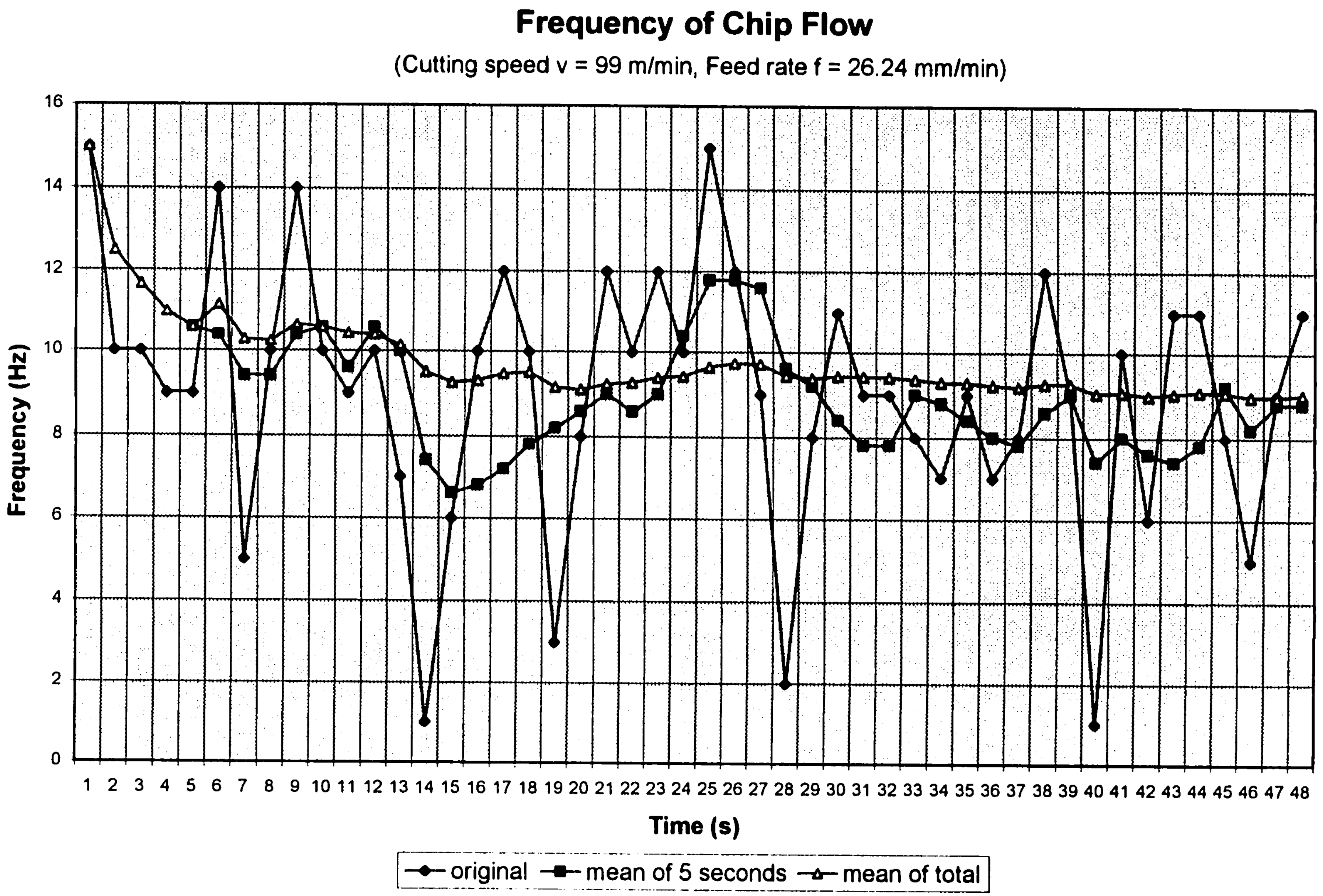
Chips' length (mm)	%
>50	5.2
>30	10.3
>20	24.1
>15	22.4
>10	20.7
<10	17.3

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 9.02 Hz
2. Average length : 17.7 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 26.24 mm/min)
Frequency (Hz)
16
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
Time (s)
original
mean of 5 seconds
mean of total

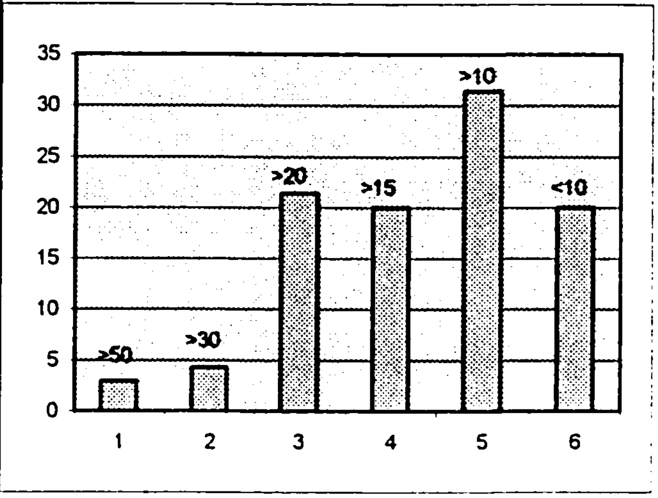
Cutting speed v = 99 m/min, Feed rate f = 27.44 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	7	7	7	
2	12	19	9.5	
3	7	26	8.666666667	
4	11	37	9.25	
5	11	48	9.6	9.6
6	13	61	10.16666667	10.8
7	15	76	10.85714286	11.4
8	8	84	10.5	11.6
9	10	94	10.44444444	11.4
10	10	104	10.4	11.2
11	3	107	9.727272727	9.2
12	10	117	9.75	8.2
13	9	126	9.692307692	8.4
14	11	137	9.785714286	8.6
15	12	149	9.933333333	9
16	4	153	9.5625	9.2
17	12	165	9.705882353	9.6
18	10	175	9.722222222	9.8
19	14	189	9.947368421	10.4
20	9	198	9.9	9.8
21	13	211	10.04761905	11.6
22	7	218	9.909090909	10.6
23	13	231	10.04347826	11.2
24	12	243	10.125	10.8
25	11	254	10.16	11.2
26	11	265	10.19230769	10.8
27	9	274	10.14814815	11.2
28	12	286	10.21428571	11
29	12	298	10.27586207	11
30	10	308	10.26666667	10.8
31	9	317	10.22580645	10.4
32	10	327	10.21875	10.6
33	6	333	10.09090909	9.4
34	8	341	10.02941176	8.6
35	14	355	10.14285714	9.4
36	13	368	10.22222222	10.2
37	13	381	10.2972973	10.8
38	10	391	10.28947368	11.6
39	13	404	10.35897436	12.6
40	14	418	10.45	12.6
41	9	427	10.41463415	11.8
42	0	427	10.16666667	9.2
43	22	449	10.44186047	11.6
44	10	459	10.43181818	11
45	11	470	10.44444444	10.4
46	11	481	10.45652174	10.8
47	8	489	10.40425532	12.4
48	12	501	10.4375	10.4

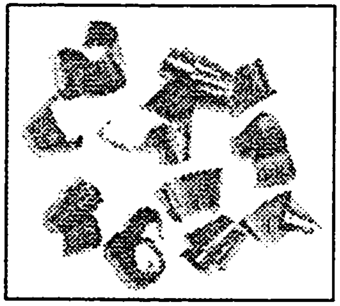
Chips' length distribution

Chips' length (mm)	%
>50	2.9
>30	4.3
>20	21.4
>15	20
>10	31.4
<10	20

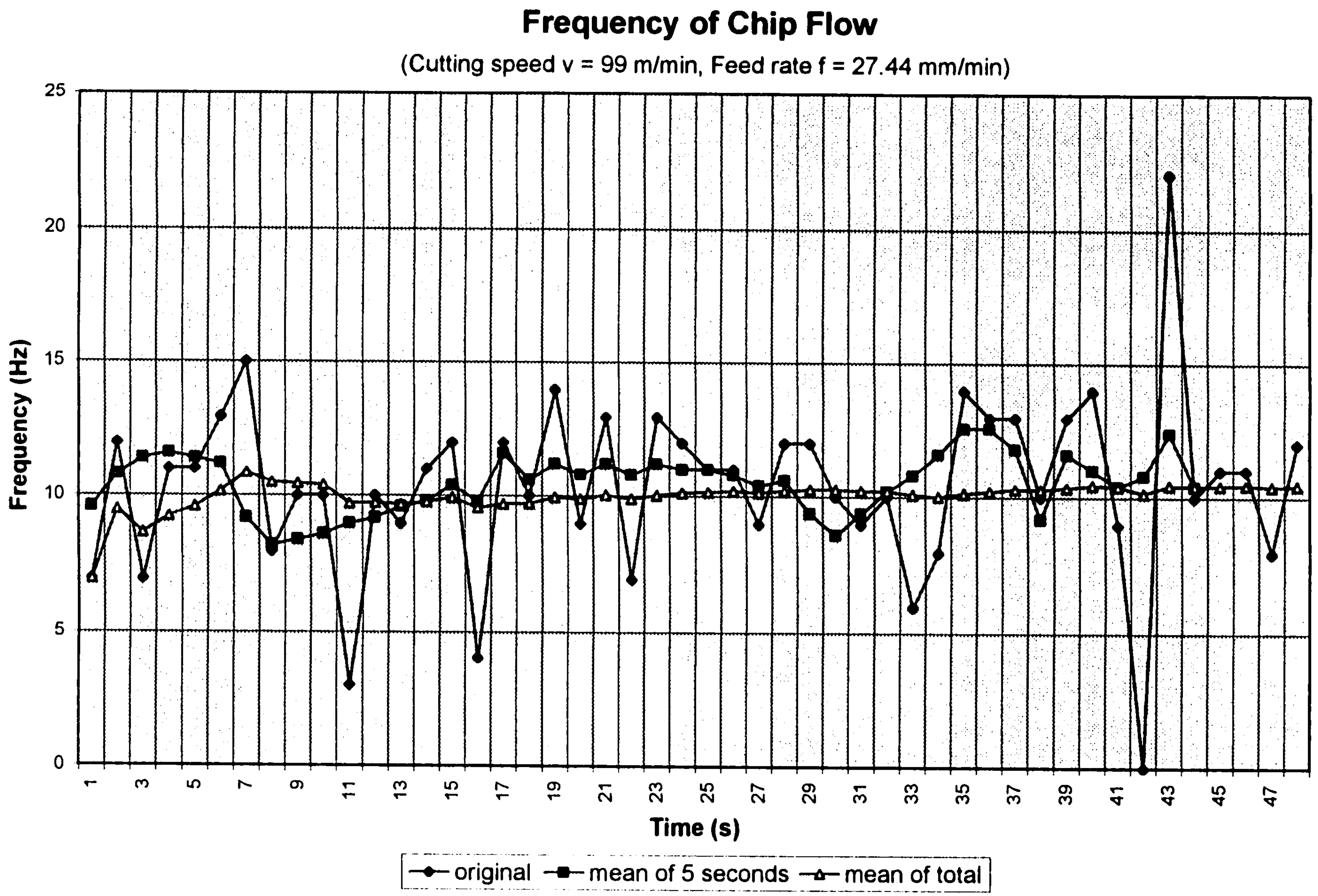
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 10.44 Hz
2. Average length : 15.1 mm
3. 28% unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 27.44 mm/min)

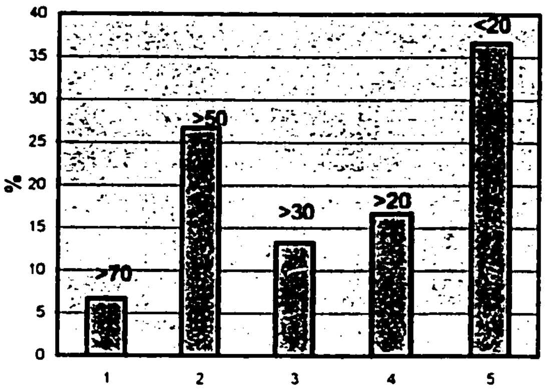
Cutting speed v = 99 m/min, Feed rate f = 28 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	7	7	7	
2	7	14	7	
3	6	20	6.666666667	6.666666667
4	5	25	6.25	6
5	7	32	6.4	6.4
6	9	41	6.833333333	6.8
7	7	48	6.857142857	6.8
8	11	59	7.375	7.8
9	7	66	7.333333333	8.2
10	6	72	7.2	8
11	9	81	7.363636364	8
12	7	88	7.333333333	8
13	8	96	7.384615385	7.4
14	6	102	7.285714286	7.2
15	7	109	7.266666667	7.4
16	6	115	7.1875	6.8
17	6	121	7.117647059	6.6
18	6	127	7.055555556	6.2
19	7	134	7.052631579	6.4
20	9	143	7.15	6.8
21	9	152	7.238095238	7.4
22	6	158	7.181818182	7.4
23	4	162	7.043478261	7
24	7	169	7.041666667	7
25	6	175	7	6.4
26	7	182	7	6
27	10	192	7.111111111	6.8
28	7	199	7.107142857	7.4
29	7	206	7.103448276	7.4
30	11	217	7.233333333	8.4
31	5	222	7.161290323	8
32	8	230	7.1875	7.6
33	6	236	7.151515152	7.4
34	8	244	7.176470588	7.6
35	8	252	7.2	7
36	6	258	7.166666667	7.2
37	8	266	7.189189189	7.2
38	5	271	7.131578947	7
39	4	275	7.051282051	6.2
40	7	282	7.05	6
41	9	291	7.097560976	6.6
42	6	297	7.071428571	6.2
43	6	303	7.046511628	6.4
44	8	311	7.068181818	7.2
45	8	319	7.088888889	7.4
46	6	325	7.065217391	6.8
47	5	330	7.021276596	6.6
48	6	336	7	6.6

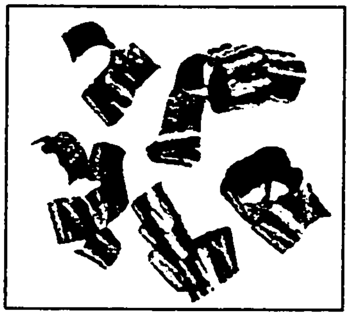
Chips' length distribution

Chips' length (mm)	%
>70	6.7
>50	26.7
>30	13.3
>20	16.7
<20	36.6

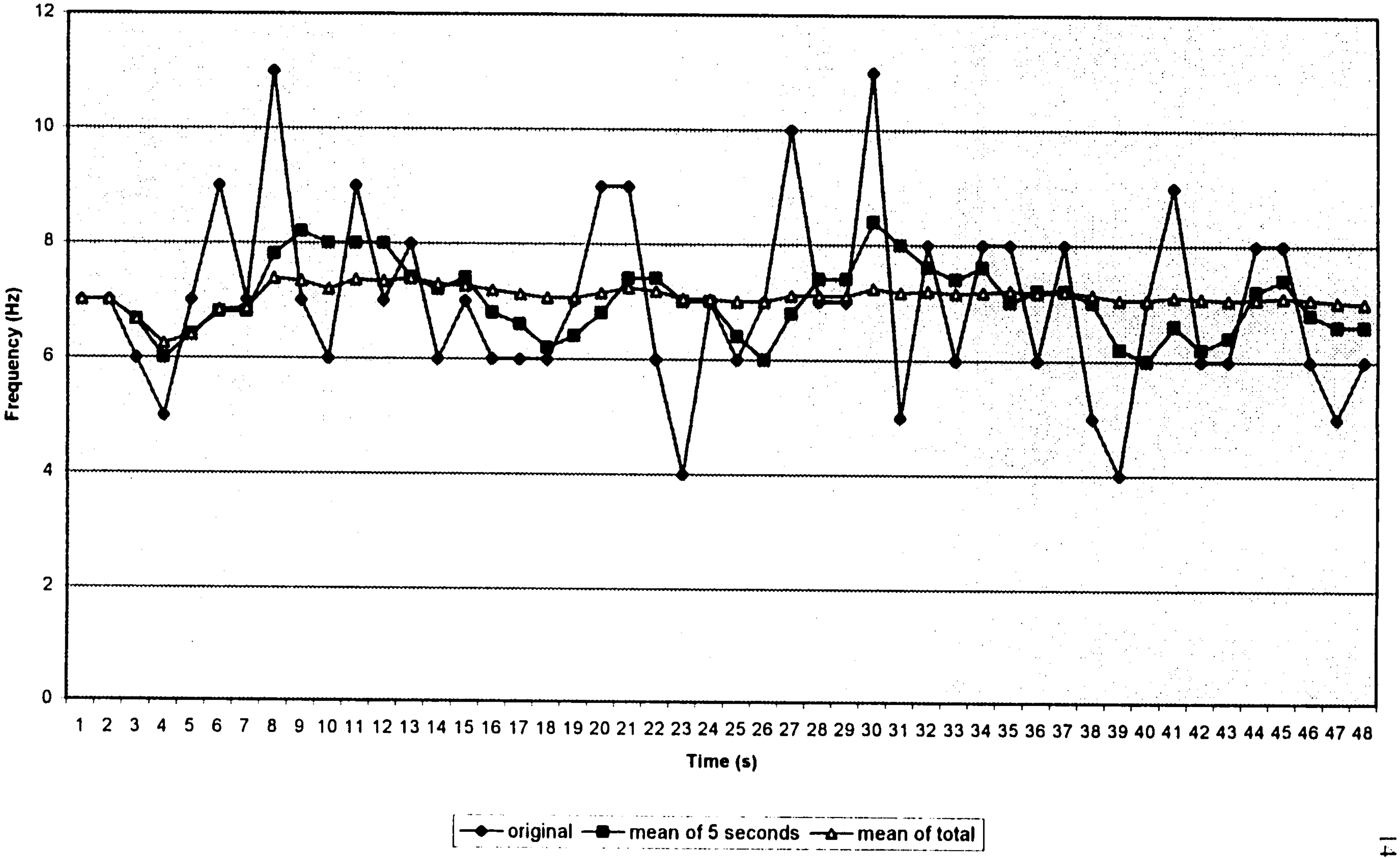
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 7 Hz
2. Average length : 32.7 mm
3. Too many unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 28 mm/min)

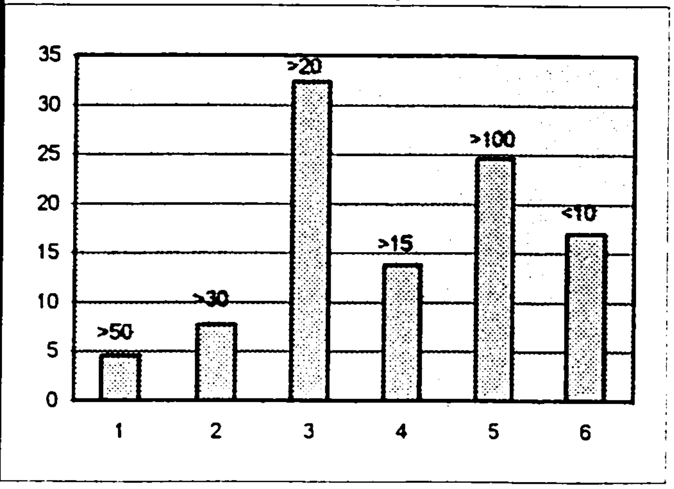
Cutting speed v = 99 m/min, Feed rate f = 28.59 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	9	9		
2	4	13	6.5	
3	7	20	6.66666667	
4	10	30	7.5	
5	10	40	8	8
6	13	53	8.83333333	8.8
7	5	58	8.28571429	9
8	11	69	8.625	9.8
9	11	80	8.88888889	10
10	10	90	9	10
11	6	96	8.72727273	8.6
12	10	106	8.83333333	9.6
13	10	116	8.92307692	9.4
14	9	125	8.92857143	9
15	5	130	8.66666667	8
16	11	141	8.8125	9
17	11	152	8.94117647	9.2
18	10	162	9	9.2
19	10	172	9.05263158	9.4
20	9	181	9.05	10.2
21	11	192	9.14285714	10.2
22	6	198	9	9.2
23	10	208	9.04347826	9.2
24	7	215	8.95833333	8.6
25	13	228	9.12	9.4
26	12	240	9.23076923	9.6
27	11	251	9.2962963	10.6
28	13	264	9.42857143	11.2
29	7	271	9.34482759	11.2
30	10	281	9.36666667	10.6
31	7	288	9.29032258	9.6
32	8	296	9.25	9
33	8	304	9.21212121	8
34	13	317	9.32352941	9.2
35	12	329	9.4	9.6
36	9	338	9.38888889	10
37	8	346	9.35135135	10
38	10	356	9.36842105	10.4
39	10	366	9.38461538	9.8
40	9	375	9.375	9.2
41	14	389	9.48780488	10.2
42	16	405	9.64285714	11.8
43	6	411	9.55813953	11
44	7	418	9.5	10.4
45	8	426	9.46666667	10.2
46	9	435	9.45652174	9.2
47	8	443	9.42553191	7.6
48	5	448	9.33333333	7.4

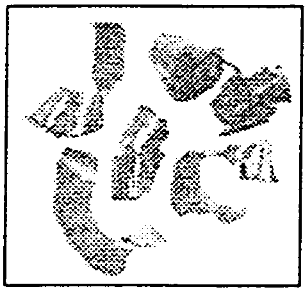
Chips length distribution

Chips' length (mm)	%
>50	4.6
>30	7.7
>20	32.3
>15	13.8
>10	24.6
<10	17

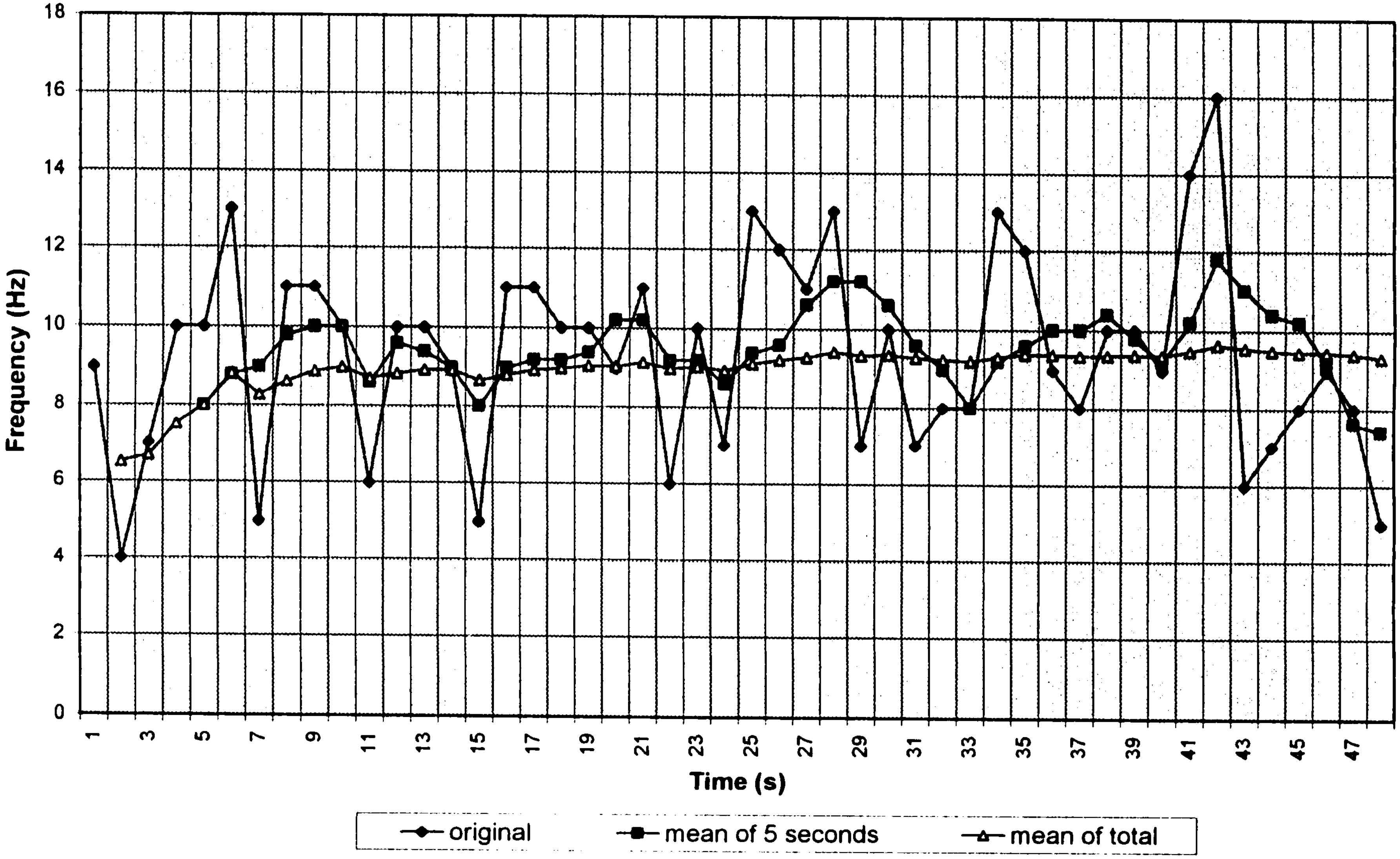
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 9.33 Hz
2. Average length : 17.3 mm
3. Too many unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 28.59 mm/min)

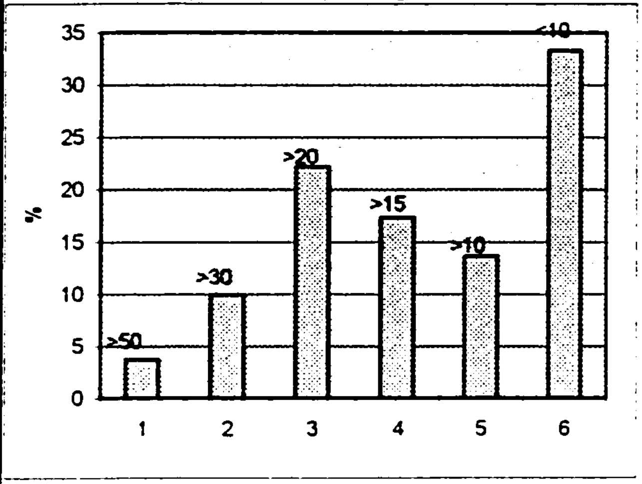
Cutting speed v = 99 m/min, Feed rate f = 29.04 mm/min

	Frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5seconds
1	7	7	7	
2	10	17	8.5	
3	7	24	8	
4	8	32	8	
5	9	41	8.2	8.2
6	10	51	8.5	8.8
7	13	64	9.142857143	9.4
8	14	78	9.75	10.8
9	2	80	8.888888889	9.6
10	9	89	8.9	9.6
11	17	106	9.636363636	11
12	11	117	9.75	10.6
13	11	128	9.846153846	10
14	13	141	10.07142857	12.2
15	8	149	9.933333333	12
16	10	159	9.9375	10.6
17	14	173	10.17647059	11.2
18	12	185	10.27777778	11.4
19	11	196	10.31578947	11
20	10	206	10.3	11.4
21	11	217	10.33333333	11.6
22	9	226	10.27272727	10.6
23	10	236	10.26086957	10.2
24	6	242	10.08333333	9.2
25	9	251	10.04	9
26	12	263	10.11538462	9.2
27	6	269	9.962962963	8.6
28	12	281	10.03571429	9
29	5	286	9.862068966	8.8
30	13	299	9.966666667	9.6
31	10	309	9.967741935	9.2
32	14	323	10.09375	10.8
33	7	330	10	9.8
34	12	342	10.05882353	11.2
35	8	350	10	10.2
36	1	351	9.75	8.4
37	11	362	9.783783784	7.8
38	9	371	9.763157895	8.2
39	9	380	9.743589744	7.6
40	9	389	9.725	7.8
41	13	402	9.804878049	10.2
42	9	411	9.785714286	9.8
43	9	420	9.76744186	9.8
44	10	430	9.772727273	10
45	12	442	9.822222222	10.6
46	10	452	9.826086957	10
47	10	462	9.829787234	10.2
48	10	472	9.833333333	10.4

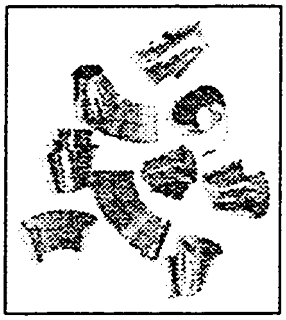
Chips length distribution

Chips' length (mm)	%
>50	3.7
>30	9.9
>20	22.2
>15	17.3
>10	13.6
<10	33.3

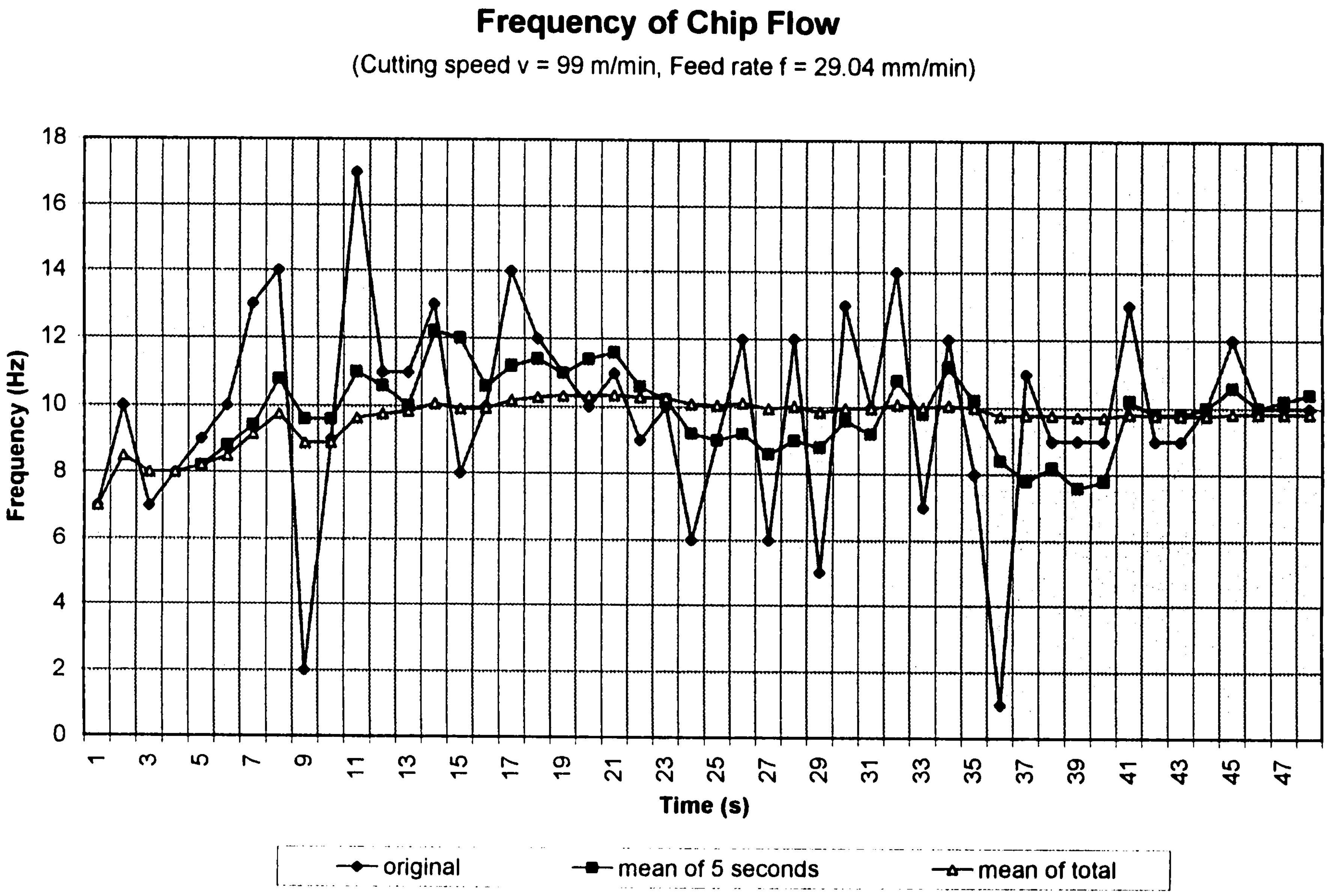
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 9.83 Hz
2. Average length : 14.1 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 29.04 mm/min)
Frequency (Hz)
0
2
4
6
8
10
12
14
16
18
Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
original
mean of 5 seconds
mean of total

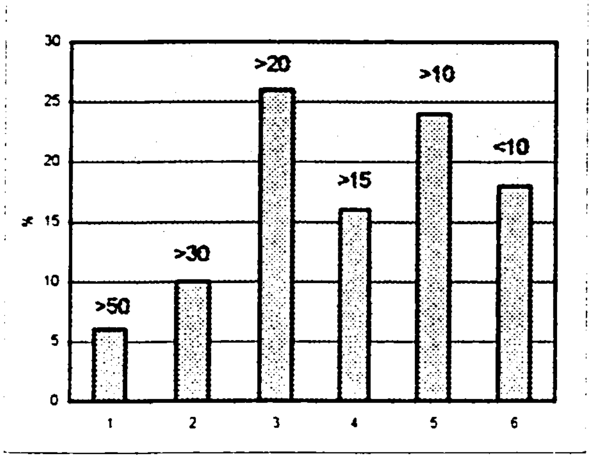
Cutting speed v = 99 m/min, Feed rate f = 29.76 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	7	7	7	
2	6	13	6.5	
3	10	23	7.666666667	
4	11	34	8.5	
5	6	40	8	8
6	7	47	7.833333333	8
7	6	53	7.571428571	8
8	6	59	7.375	7.2
9	10	69	7.666666667	7
10	11	80	8	8
11	8	88	8	8.2
12	7	95	7.916666667	8.4
13	7	102	7.846153846	8.6
14	7	109	7.785714286	8
15	6	115	7.666666667	7
16	10	125	7.8125	7.4
17	6	131	7.705882353	7.2
18	8	139	7.722222222	7.4
19	12	151	7.947368421	8.4
20	9	160	8	9
21	10	170	8.095238095	9
22	8	178	8.090909091	9.4
23	10	188	8.173913043	9.8
24	7	195	8.125	8.8
25	9	204	8.16	8.8
26	10	214	8.230769231	8.8
27	9	223	8.259259259	9
28	6	229	8.178571429	8.2
29	8	237	8.172413793	8.4
30	9	246	8.2	8.4
31	8	254	8.193548387	8
32	5	259	8.09375	7.2
33	9	268	8.121212121	7.8
34	9	277	8.147058824	8
35	9	286	8.171428571	8
36	6	292	8.111111111	7.6
37	7	299	8.081081081	8
38	12	311	8.184210526	8.6
39	6	317	8.128205128	8
40	9	326	8.15	8
41	9	335	8.170731707	8.6
42	6	341	8.119047619	8.4
43	9	350	8.139534884	7.8
44	9	359	8.159090909	8.4
45	10	369	8.2	8.6
46	11	380	8.260869565	9
47	10	390	8.29787234	9.8
48	10	400	8.333333333	10

Chips' length distribution

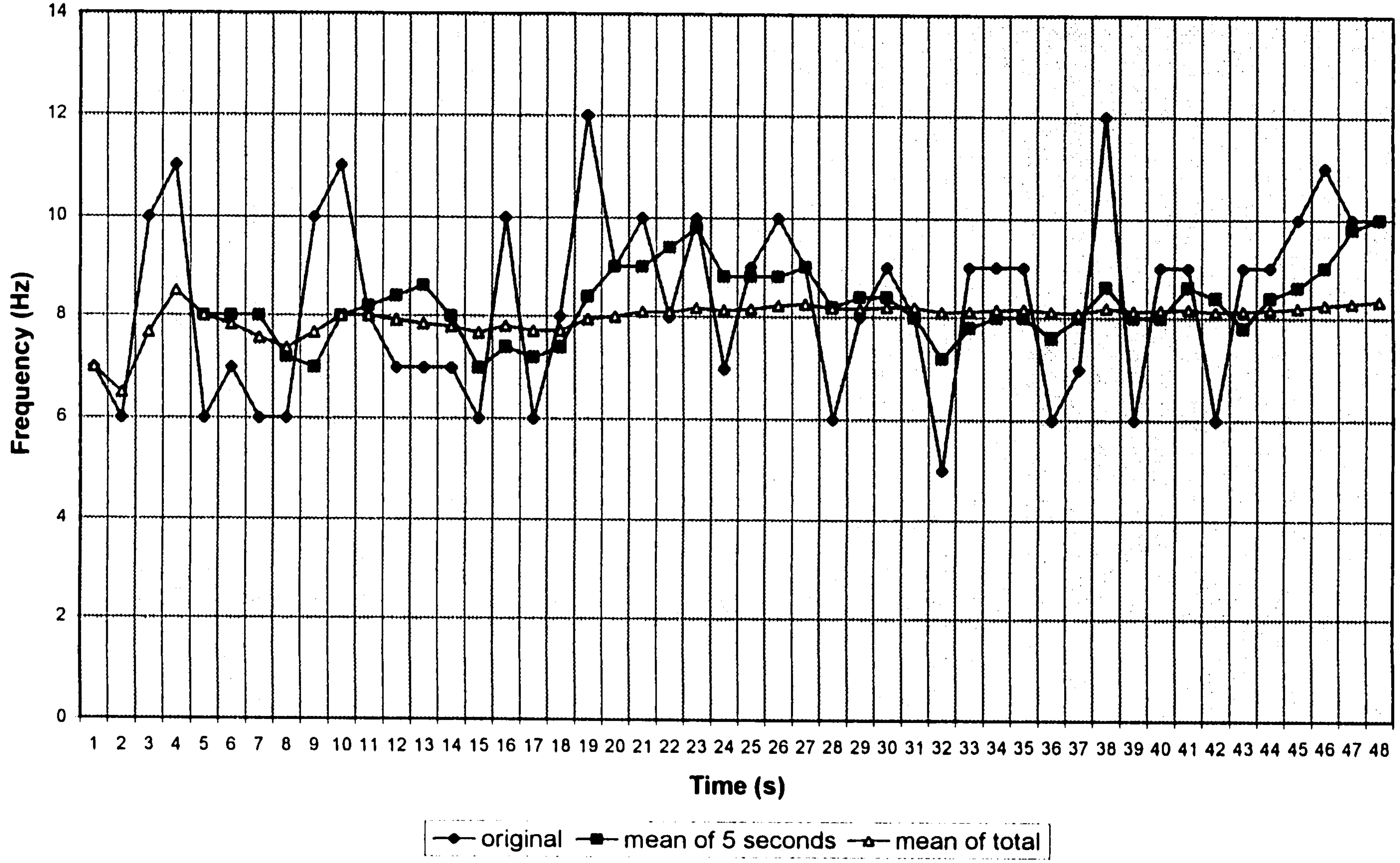
Chips' length (mm)	%
>50	6
>30	10
>20	26
>15	16
>10	24
<10	18

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 8.3 Hz
2. Average length : 17.8 mm
3. Too many unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 29.76 mm/min)

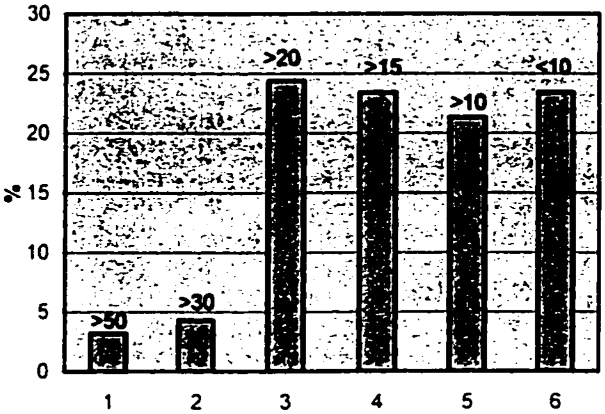
Cutting speed v = 99 m/min, Feed rate f = 30.35 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	3	3	3	
2	6	9	4.5	
3	7	16	5.333333333	
4	9	25	6.25	
5	6	31	6.2	6.2
6	10	41	6.833333333	7.6
7	10	51	7.285714286	8.4
8	12	63	7.875	9.4
9	10	73	8.111111111	9.6
10	11	84	8.4	10.6
11	12	96	8.727272727	11
12	14	110	9.166666667	11.8
13	11	121	9.307692308	11.6
14	12	133	9.5	12
15	6	139	9.266666667	11
16	9	148	9.25	10.4
17	13	161	9.470588235	10.2
18	10	171	9.5	10
19	13	184	9.684210526	10.2
20	11	195	9.75	11.2
21	5	200	9.523809524	10.4
22	12	212	9.636363636	10.2
23	6	218	9.47826087	9.4
24	13	231	9.625	9.4
25	12	243	9.72	9.6
26	10	253	9.730769231	10.6
27	11	264	9.777777778	10.4
28	11	275	9.821428571	11.4
29	7	282	9.724137931	10.2
30	14	296	9.866666667	10.6
31	6	302	9.741935484	9.8
32	7	309	9.65625	9
33	9	318	9.636363636	8.6
34	11	329	9.676470588	9.4
35	8	337	9.628571429	8.2
36	9	346	9.611111111	8.8
37	11	357	9.648648649	9.6
38	12	369	9.710526316	10.2
39	8	377	9.666666667	9.6
40	9	386	9.65	9.8
41	7	393	9.585365854	9.4
42	12	405	9.642857143	9.6
43	7	412	9.581395349	8.6
44	10	422	9.590909091	9
45	10	432	9.6	9.2
46	14	446	9.695652174	10.6
47	13	459	9.765957447	10.8
48	10	469	9.770833333	11.4

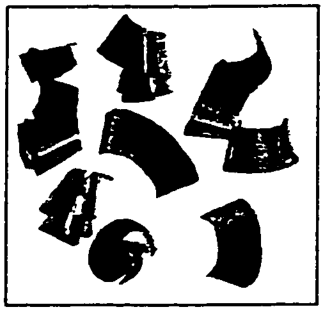
Chips' length distribution

Chips' length (mm)	%
>50	3.2
>30	4.3
>20	24.4
>15	23.4
>10	21.3
<10	23.4

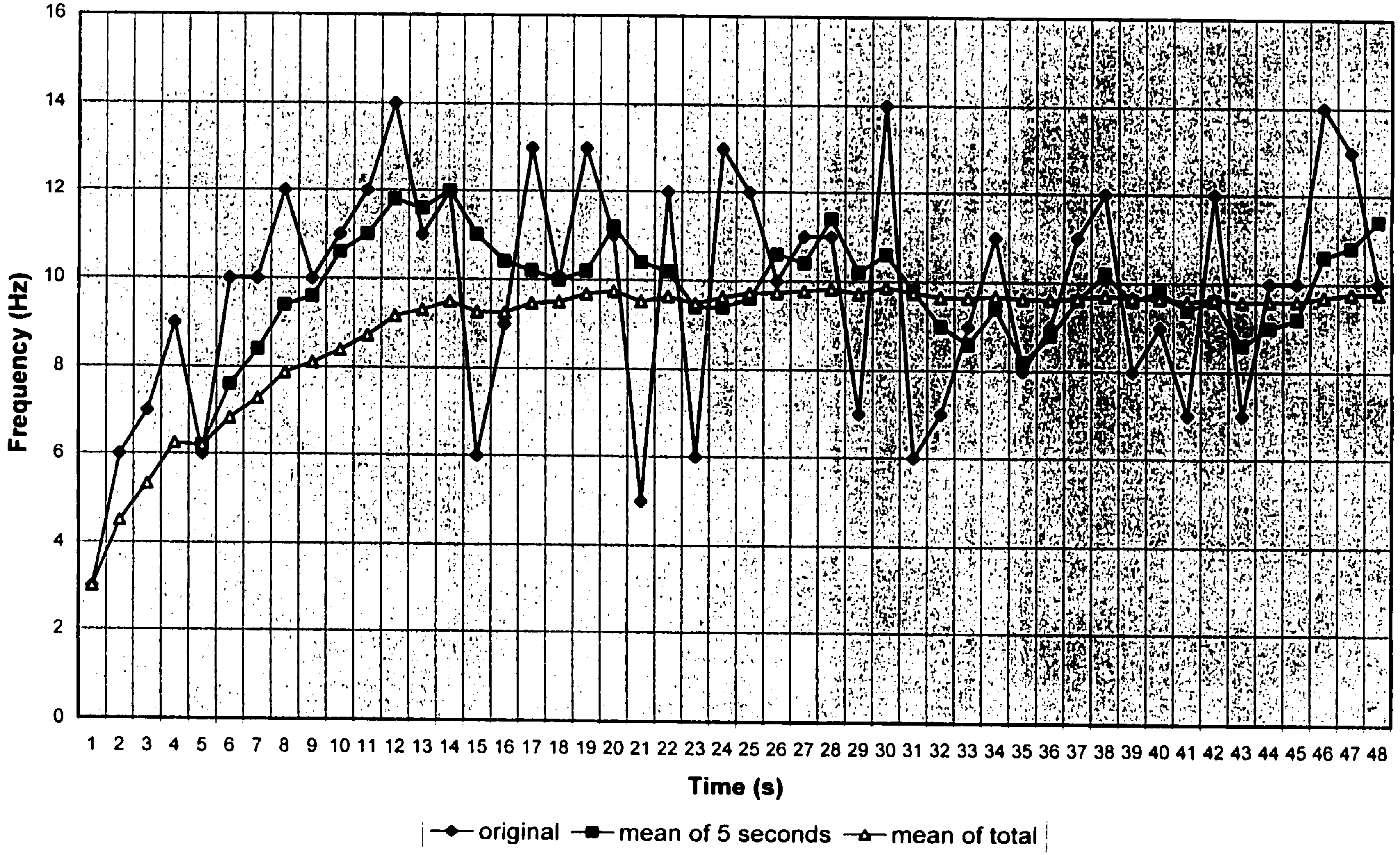
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 9.77 Hz
2. Average length : 15.7 mm
3. Too many unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 30.35 mm/min)

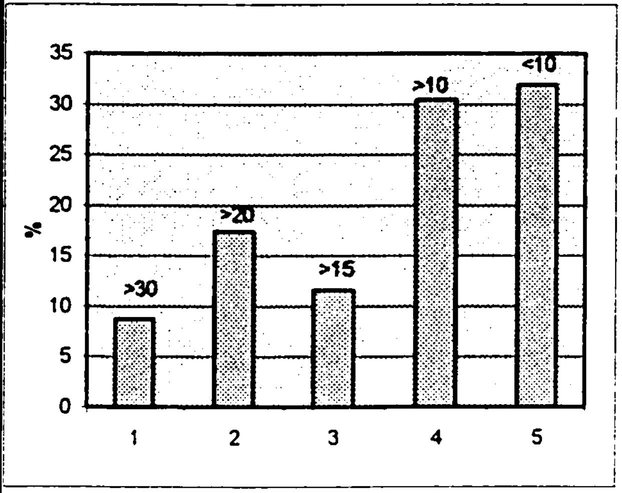
Cutting speed v = 99 m/min, Feed rate f = 30.93 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	8	8	8	
2	6	14	7	
3	6	20	6.666666667	
4	6	26	6.5	
5	6	32	6.4	6.4
6	9	41	6.833333333	6.6
7	6	47	6.714285714	6.6
8	4	51	6.375	6.2
9	8	59	6.555555556	6.6
10	9	68	6.8	7.2
11	7	75	6.818181818	6.8
12	11	86	7.166666667	7.8
13	9	95	7.307692308	8.8
14	13	108	7.714285714	9.8
15	13	121	8.066666667	10.6
16	10	131	8.1875	11.2
17	11	142	8.352941176	11.2
18	13	155	8.611111111	12
19	13	168	8.842105263	12
20	10	178	8.9	11.4
21	10	188	8.952380952	11.4
22	5	193	8.772727273	10.2
23	10	203	8.826086957	9.6
24	10	213	8.875	9
25	10	223	8.92	9
26	13	236	9.076923077	9.6
27	7	243	9	10
28	13	256	9.142857143	10.6
29	9	265	9.137931034	10.4
30	13	278	9.266666667	11
31	10	288	9.290322581	10.4
32	8	296	9.25	10.6
33	5	301	9.121212121	9
34	9	310	9.117647059	9
35	10	320	9.142857143	8.4
36	8	328	9.111111111	8
37	10	338	9.135135135	8.4
38	9	347	9.131578947	9.2
39	9	356	9.128205128	9.2
40	11	367	9.175	9.4
41	12	379	9.243902439	10.2
42	9	388	9.238095238	10
43	8	396	9.209302326	9.8
44	6	402	9.136363636	9.2
45	11	413	9.177777778	9.2
46	8	421	9.152173913	8.4
47	12	433	9.212765957	9
48	10	443	9.229166667	9.4

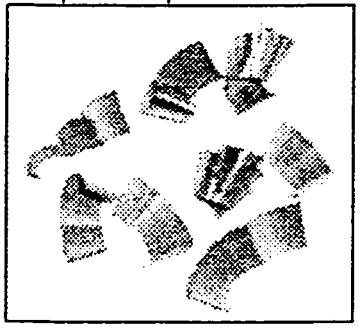
Chips' length distribution

Chips' length (mm)	%
>30	8.7
>20	17.4
>15	11.6
>10	30.4
<10	31.9

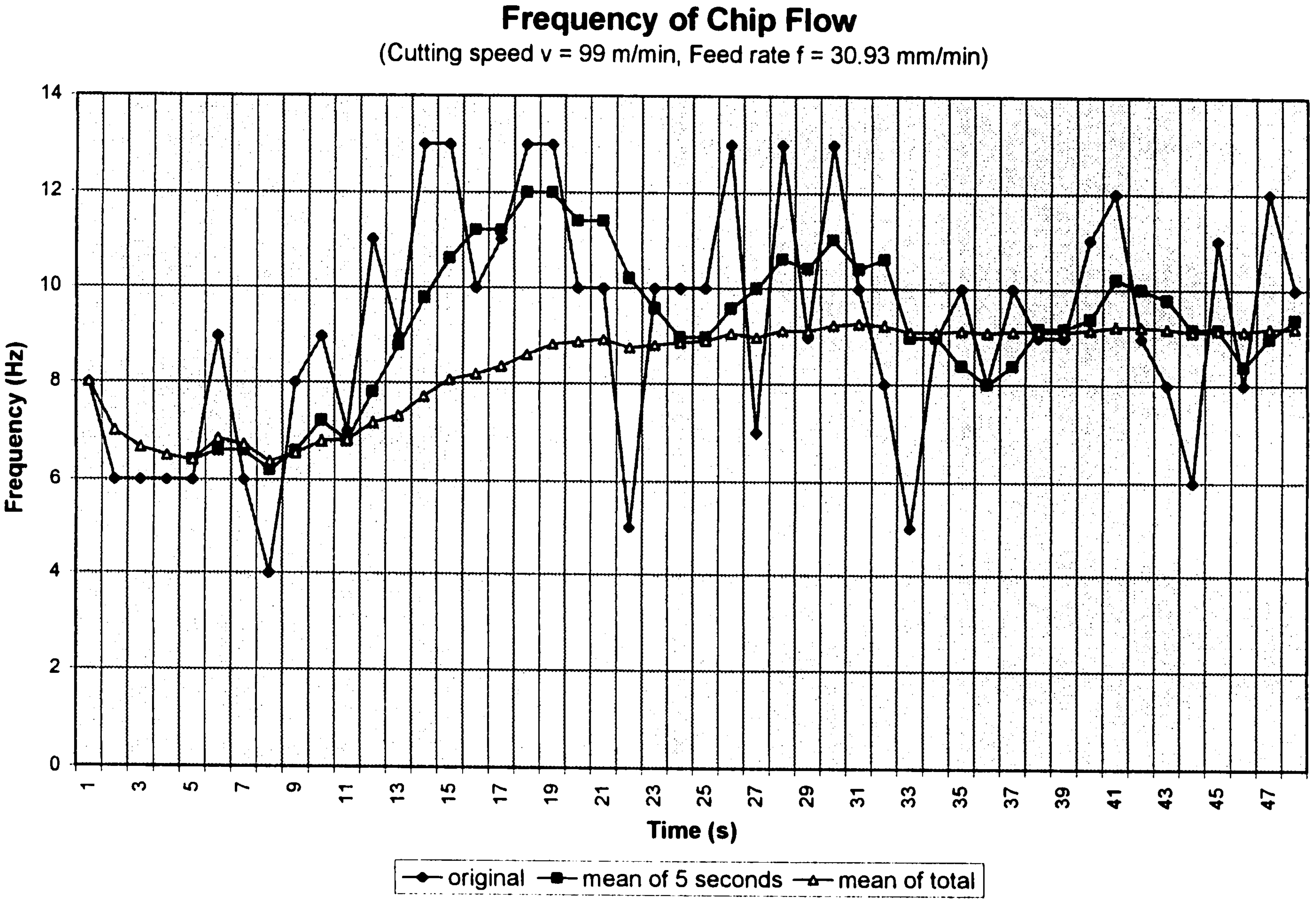
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 9.23 Hz
2. Average length : 14.1 mm
3. Too many unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 30.93 mm/min)
Frequency (Hz)
14
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
Time (s)
original
mean of 5 seconds
mean of total

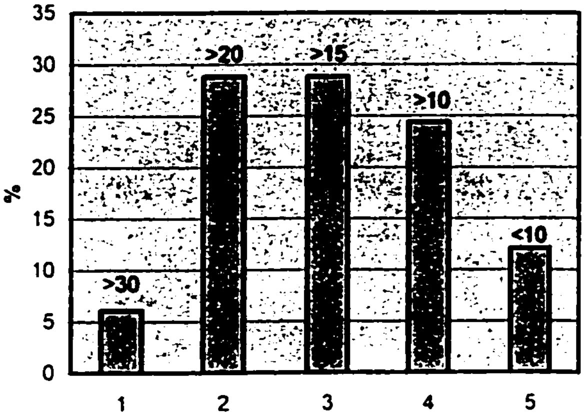
Cutting speed v = 99 m/min, Feed rate f = 33.87 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	13	13	13	
2	14	27	13.5	
3	8	35	11.66666667	
4	10	45	11.25	
5	11	56	11.2	11.2
6	12	68	11.33333333	11
7	12	80	11.42857143	10.6
8	6	86	10.75	10.2
9	10	96	10.66666667	10.2
10	10	106	10.6	10
11	9	115	10.45454545	9.4
12	8	123	10.25	8.6
13	11	134	10.30769231	9.6
14	6	140	10	8.8
15	12	152	10.13333333	9.2
16	10	162	10.125	9.4
17	11	173	10.17647059	10
18	11	184	10.22222222	10
19	13	197	10.36842105	11.4
20	7	204	10.2	10.4
21	11	215	10.23809524	10.6
22	11	226	10.27272727	10.6
23	15	241	10.47826087	11.4
24	12	253	10.54166667	11.2
25	13	266	10.64	12.4
26	16	282	10.84615385	13.4
27	14	296	10.96296296	14
28	15	311	11.10714286	14
29	12	323	11.13793103	14
30	15	338	11.26666667	14.4
31	12	350	11.29032258	13.6
32	11	361	11.28125	13
33	15	376	11.39393939	13
34	10	386	11.35294118	12.6
35	11	397	11.34285714	11.8
36	16	413	11.47222222	12.6
37	14	427	11.54054054	13.2
38	13	440	11.57894737	12.8
39	11	451	11.56410256	13
40	7	458	11.45	12.2
41	10	468	11.41463415	11
42	9	477	11.35714286	10
43	10	487	11.3255814	9.4
44	10	497	11.29545455	9.2
45	10	507	11.26666667	9.8

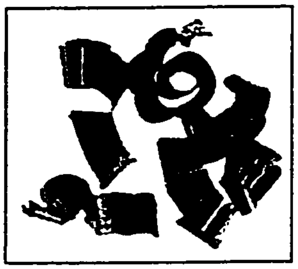
Chips' length distribution

Chips' length (mm)	%
>30	6.1
>20	28.8
>15	28.8
>10	24.4
<10	12.1

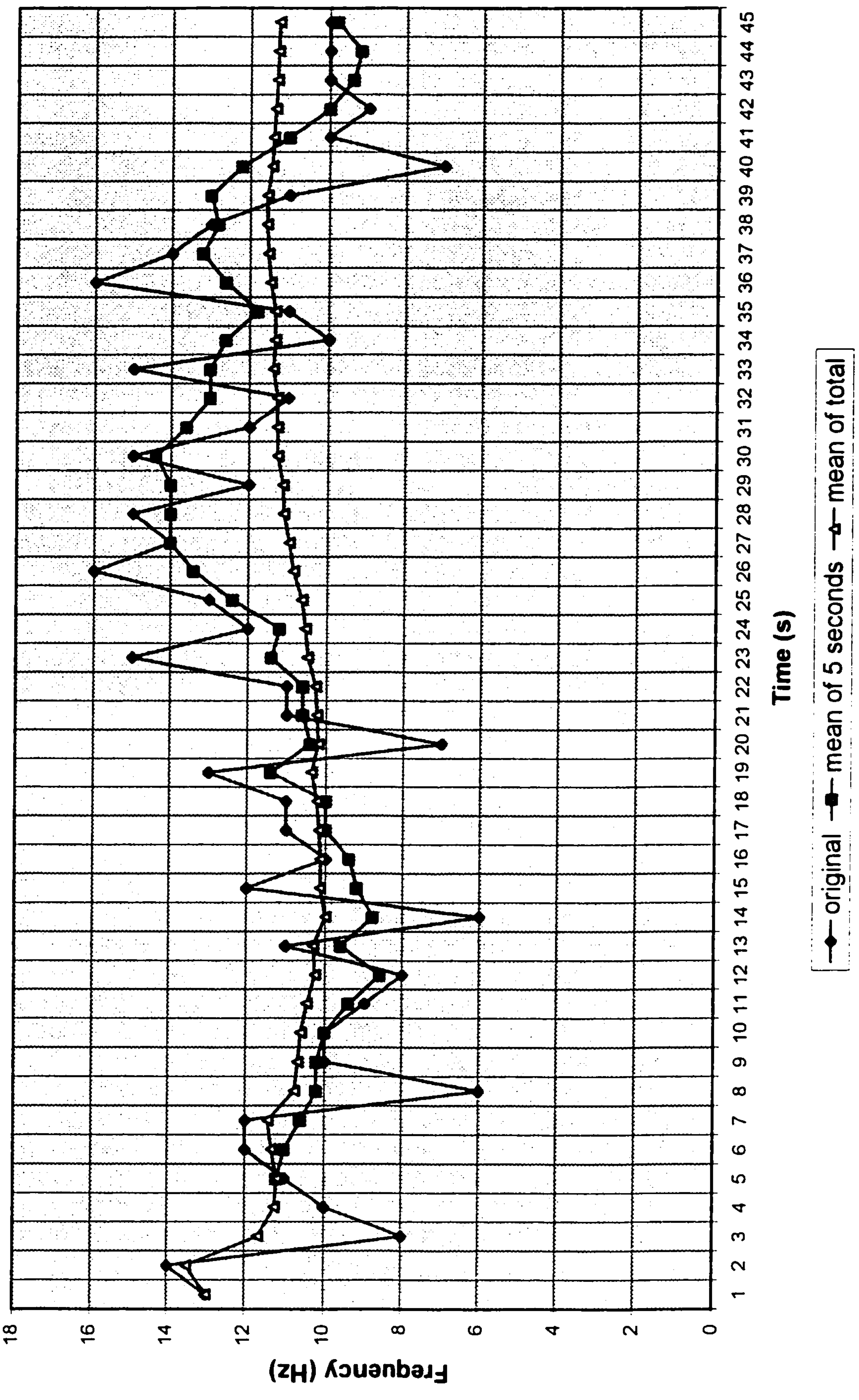
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 11.27 Hz
2. Average length : 15.5 mm
3. 34.9% unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 33.87 mm/min)

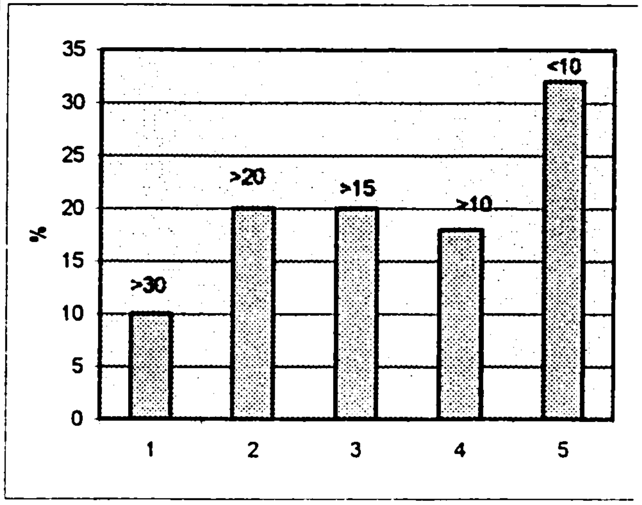
Cutting speed v = 99 m/min, Feed rate f = 36.8 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	14	14	14	
2	10	24	12	
3	16	40	13.33333333	
4	14	54	13.5	
5	9	63	12.6	12.6
6	12	75	12.5	12.2
7	16	91	13	13.4
8	15	106	13.25	13.2
9	13	119	13.22222222	13
10	14	133	13.3	14
11	14	147	13.36363636	14.4
12	14	161	13.41666667	14
13	6	167	12.84615385	12.2
14	12	179	12.78571429	12
15	20	199	13.26666667	13.2
16	12	211	13.1875	12.8
17	12	223	13.11764706	12.4
18	9	232	12.88888889	13
19	15	247	13	13.6
20	15	262	13.1	12.6
21	15	277	13.19047619	13.2
22	10	287	13.04545455	12.8
23	14	301	13.08695652	13.8
24	14	315	13.125	13.6
25	2	317	12.68	11
26	12	329	12.65384615	10.4
27	11	340	12.59259259	10.6
28	15	355	12.67857143	10.8
29	10	365	12.5862069	10
30	19	384	12.8	13.4
31	13	397	12.80645161	13.6
32	15	412	12.875	14.4
33	16	428	12.96969697	14.6
34	11	439	12.91176471	14.8
35	10	449	12.82857143	13
36	17	466	12.94444444	13.8
37	15	481	13	13.8
38	11	492	12.94736842	12.8
39	12	504	12.92307692	13
40	15	519	12.975	14
41	19	538	13.12195122	14.4

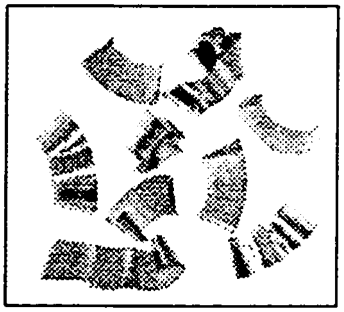
Chips' length distribution

Chips' length (mm)	%
>30	10
>20	20
>15	20
>10	18
<10	32

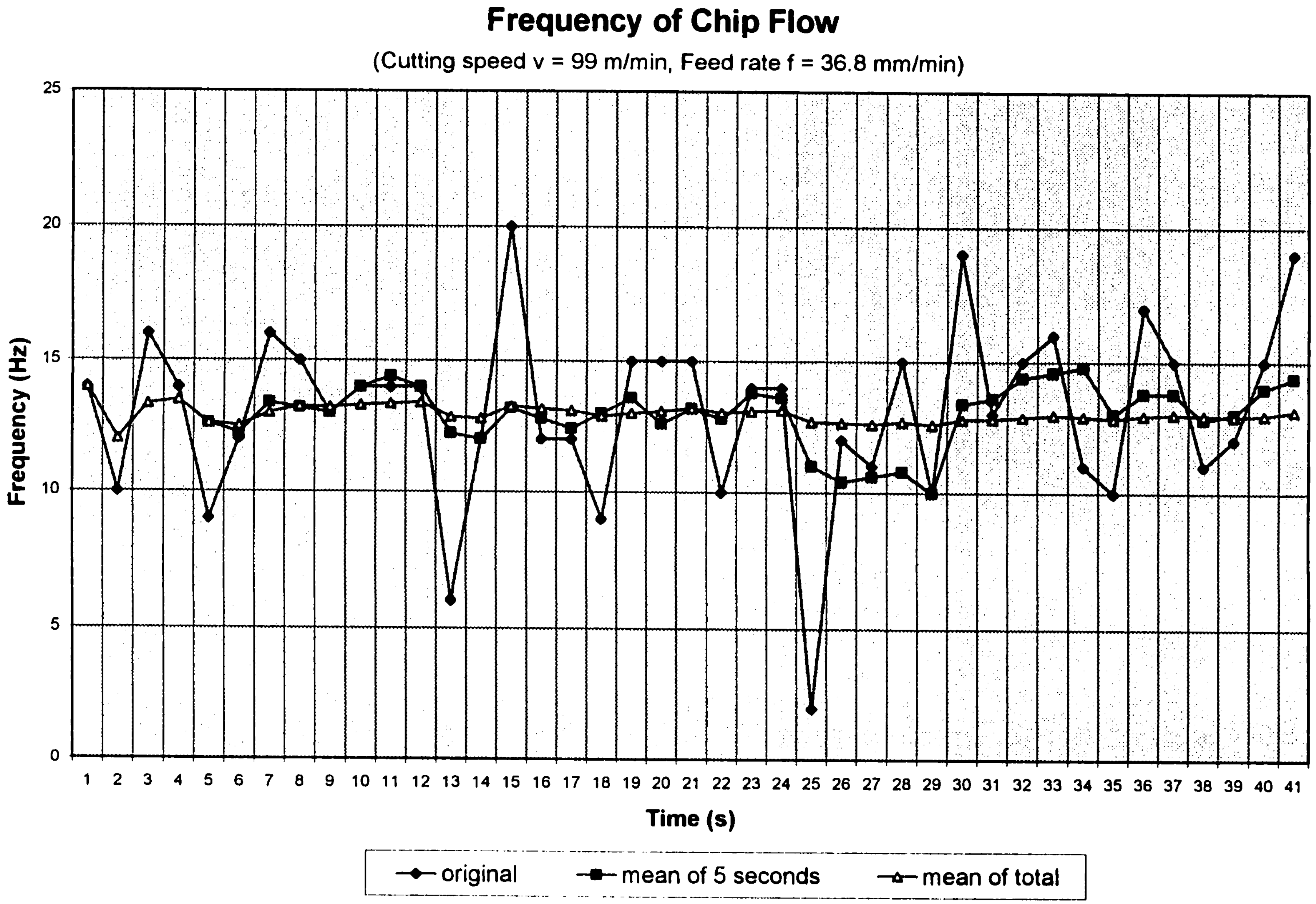
Graphics of chips length distributi



Sample of chips



1. Total mean of frequency: 13.1 Hz
2. Average length : 15 mm
3. 30% unacceptable
4. Unacceptbale



Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 36.8 mm/min)

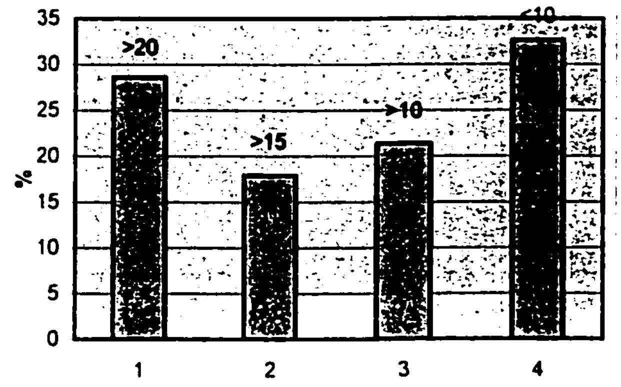
Cutting speed v = 99 m/min, Feed rate f = 39.73 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	8	8	8	
2	11	19	9.5	
3	13	32	10.66666667	
4	14	46	11.5	
5	11	57	11.4	11.4
6	17	74	12.33333333	13.2
7	12	86	12.28571429	13.4
8	11	97	12.125	13
9	23	120	13.33333333	14.8
10	14	134	13.4	15.4
11	17	151	13.72727273	15.4
12	14	165	13.75	15.8
13	13	178	13.69230769	16.2
14	17	195	13.92857143	15
15	13	208	13.86666667	14.8
16	20	228	14.25	15.4
17	17	245	14.41176471	16
18	12	257	14.27777778	15.8
19	11	268	14.10526316	14.6
20	15	283	14.15	15
21	15	298	14.19047619	14
22	4	302	13.72727273	11.4
23	15	317	13.7826087	12
24	18	335	13.95833333	13.4
25	12	347	13.88	12.8
26	14	361	13.88461538	12.6
27	18	379	14.03703704	15.4
28	18	397	14.17857143	16
29	15	412	14.20689655	15.4
30	21	433	14.43333333	17.2
31	7	440	14.19354839	15.8
32	20	460	14.375	16.2
33	13	473	14.33333333	15.2
34	16	489	14.38235294	15.4
35	17	506	14.45714286	14.6
36	15	521	14.47222222	16.2
37	8	529	14.2972973	13.8
38	15	544	14.31578947	14.2

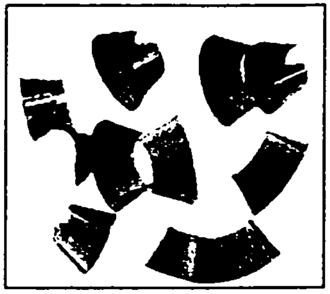
Chips length distribution

Chips' length (mm)	%
>20	28.6
>15	17.9
>10	21.4
<10	32.6

Graphics of chips length distribution



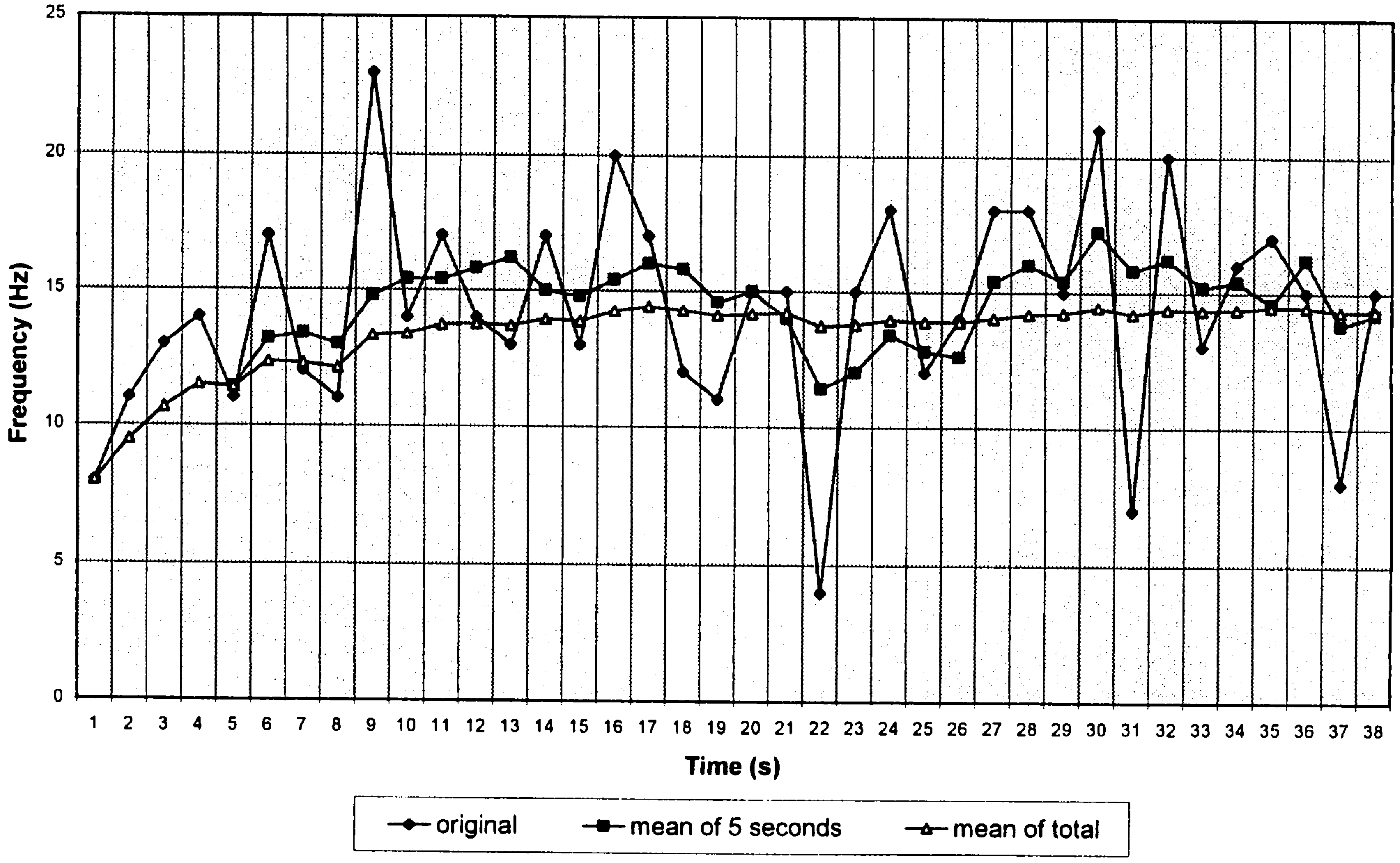
Sample of chips



1. Total mean of frequency: 14.2 Hz
2. Average length : 13.8 mm
3. 28.6% unacceptable
4. Unacceptbale

Frequency of Chip Flow

(Cutting speed v = 99 m/min, Feed rate f = 39.73 mm/min)



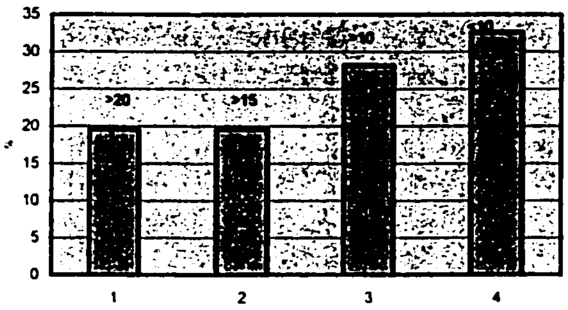
Cutting speed v = 99 m/min, Feed rate f = 45.6 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	15	15	15	
2	13	28	14	
3	19	47	15.66666667	
4	18	65	16.25	
5	14	79	15.8	15.8
6	12	91	15.16666667	15.2
7	17	108	15.42857143	16
8	22	130	16.25	16.6
9	18	148	16.44444444	16.6
10	11	159	15.9	16
11	12	171	15.54545455	16
12	16	187	15.58333333	15.8
13	17	204	15.69230769	14.8
14	11	215	15.35714286	13.4
15	16	231	15.4	14.4
16	17	248	15.5	15.4
17	15	263	15.47058824	15.2
18	16	279	15.5	15
19	15	294	15.47368421	15.8
20	15	309	15.45	15.6
21	14	323	15.38095238	15
22	20	343	15.59090909	16
23	11	354	15.39130435	15
24	11	365	15.20833333	14.2
25	11	376	15.04	13.4
26	15	391	15.03846154	13.6
27	3	394	14.59259259	10.2
28	17	411	14.67857143	11.4
29	18	429	14.79310345	12.8
30	16	445	14.83333333	13.8

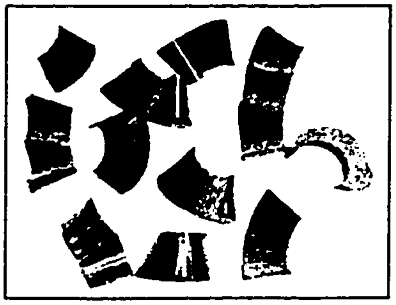
Chips length distribution

Chips' length (mm)	%
>20	19.6
>15	19.6
>10	28.2
<10	32.6

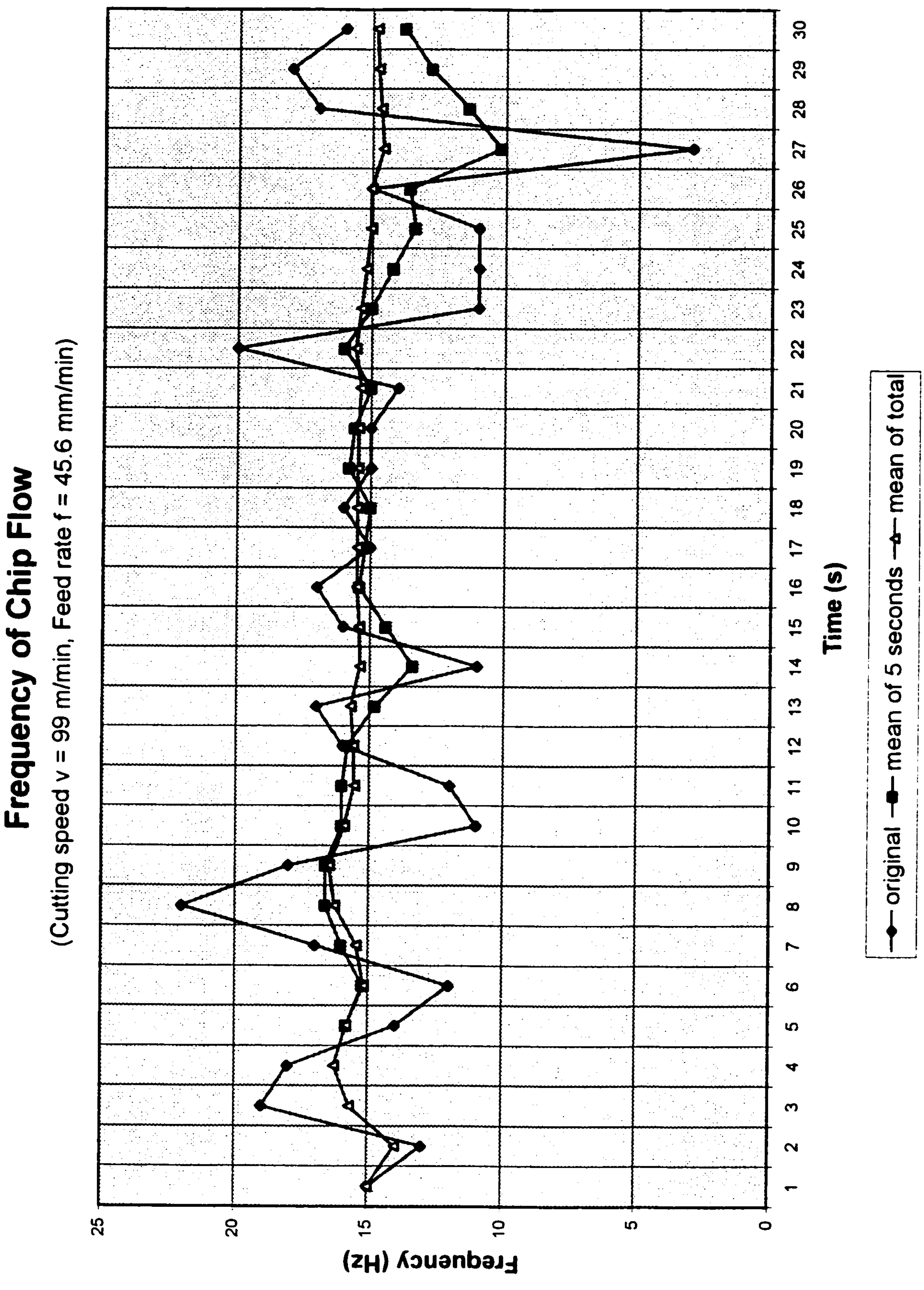
Graphics of chips length distribution



Sample of chips



1. Total mean of frequency: 14.83 Hz
2. Average length : 12.9 mm
3. 19.6% unacceptable
4. Unacceptbale


Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 45.6 mm/min)
Frequency (Hz)
25
20
15
10
5
0
Time (s)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
original
mean of 5 seconds
mean of total

Cutting speed v = 99 m/min, Feed rate f = 52.64 mm/min

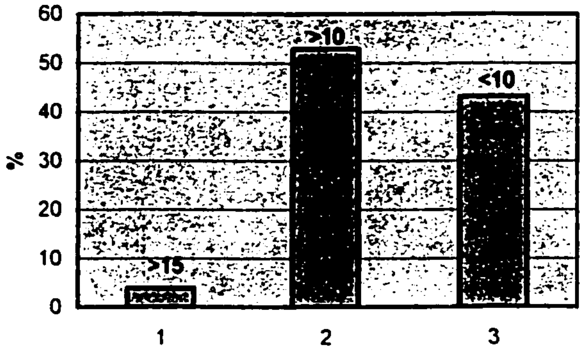
	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	13	13	13	
2	18	31	15.5	
3	22	53	17.66666667	
4	17	70	17.5	
5	22	92	18.4	18.4
6	12	104	17.33333333	18.2
7	28	132	18.85714286	20.2
8	22	154	19.25	20.2
9	8	162	18	18.4
10	27	189	18.9	19.4
11	18	207	18.81818182	20.6
12	1	208	17.33333333	15.2
13	16	224	17.23076923	14
14	9	233	16.64285714	14.2
15	0	233	15.53333333	8.8
16	22	255	15.9375	9.6
17	21	276	16.23529412	13.6
18	21	297	16.5	14.6
19	7	304	16	14.2
20	5	309	15.45	15.2
21	26	335	15.95238095	16
22	14	349	15.86363636	14.6
23	15	364	15.82608696	13.4
24	10	374	15.58333333	14
25	0	374	14.96	13
26	21	395	15.19230769	12

1. Total mean of frequency: 15.19 Hz
2. Average length : 10.2 mm
3. No unacceptable and few acceptable
4. Ideal

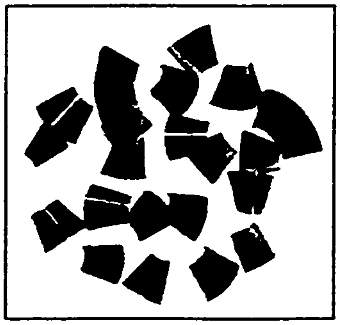
Chips' length distribution

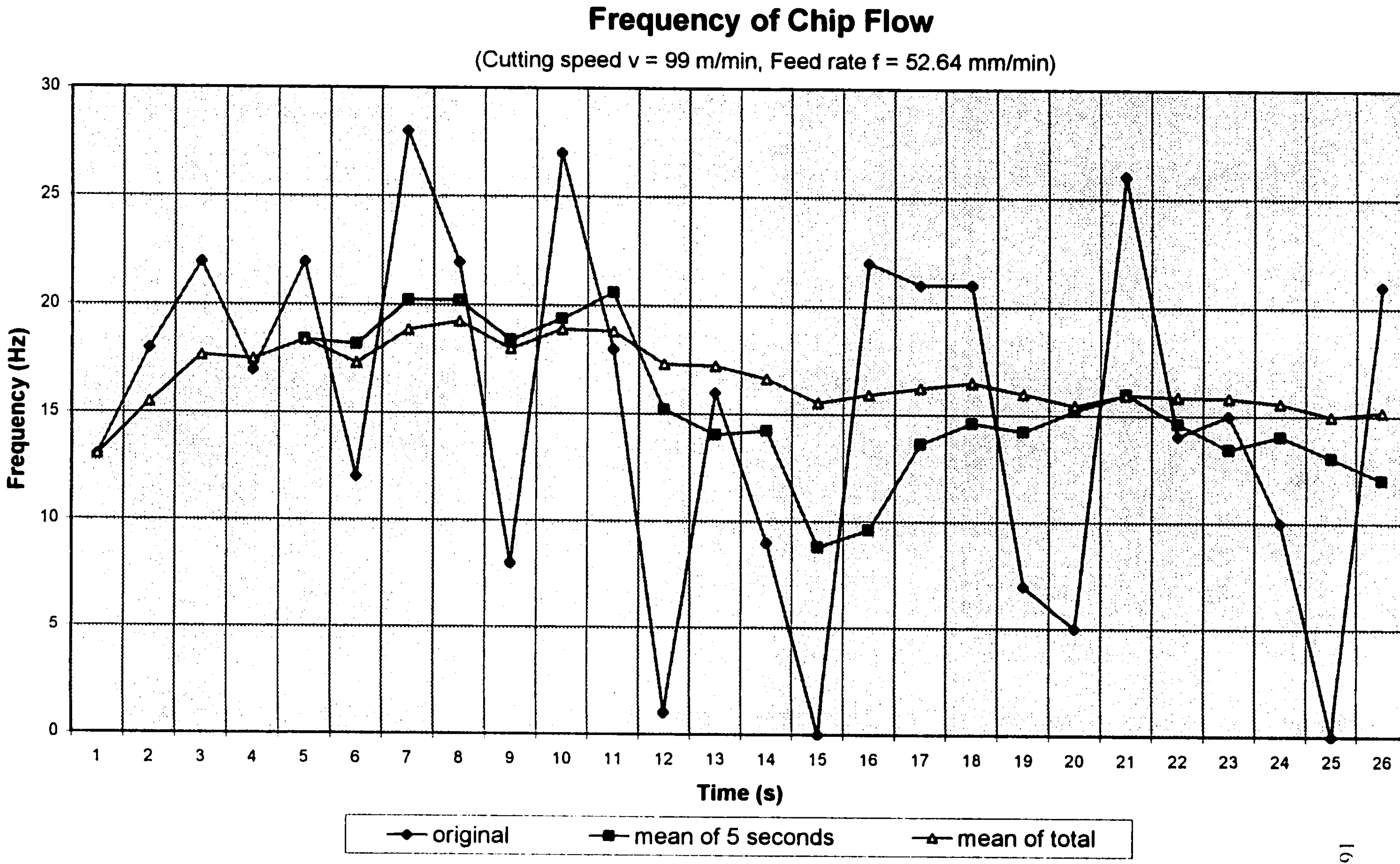
Chips' length (mm)	%
>15	3.9
>10	52.9
<10	43.2

Graphics of chips length distribution



Sample of chips




Frequency of Chip Flow
(Cutting speed v = 99 m/min, Feed rate f = 52.64 mm/min)
Frequency (Hz)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
Time (s)
original
mean of 5 seconds
mean of total

Cutting speed v = 88 m/min, Feed rate f = 28 mm/min

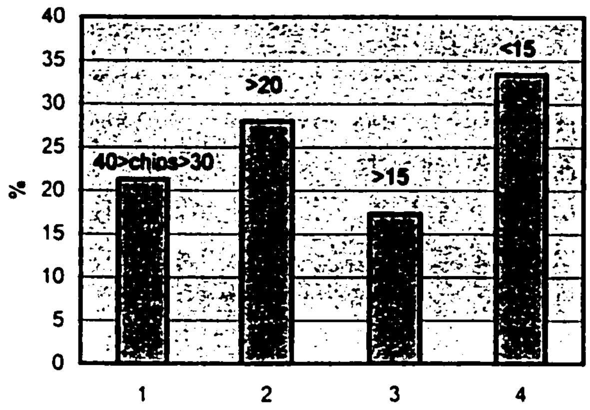
	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	5	5	5	
2	12	17	8.5	
3	13	30	10	
4	12	42	10.5	
5	13	55	11	11
6	14	69	11.5	12.8
7	12	81	11.57142857	12.8
8	17	98	12.25	13.6
9	11	109	12.11111111	13.4
10	11	120	12	13
11	14	134	12.18181818	13
12	12	146	12.16666667	13
13	16	162	12.46153846	12.8
14	14	176	12.57142857	13.4
15	13	189	12.6	13.8
16	12	201	12.5625	13.4
17	11	212	12.47058824	13.2
18	12	224	12.44444444	12.4
19	11	235	12.36842105	11.8
20	11	246	12.3	11.4
21	10	256	12.19047619	11
22	12	268	12.18181818	11.2
23	11	279	12.13043478	11
24	5	284	11.83333333	9.8
25	11	295	11.8	9.8
26	13	308	11.84615385	10.4
27	9	317	11.74074074	9.8
28	12	329	11.75	10

1. Total mean of frequency: 11.75 Hz
2. Average length : 18.27 mm
3. 21% unacceptable
4. Unacceptbale

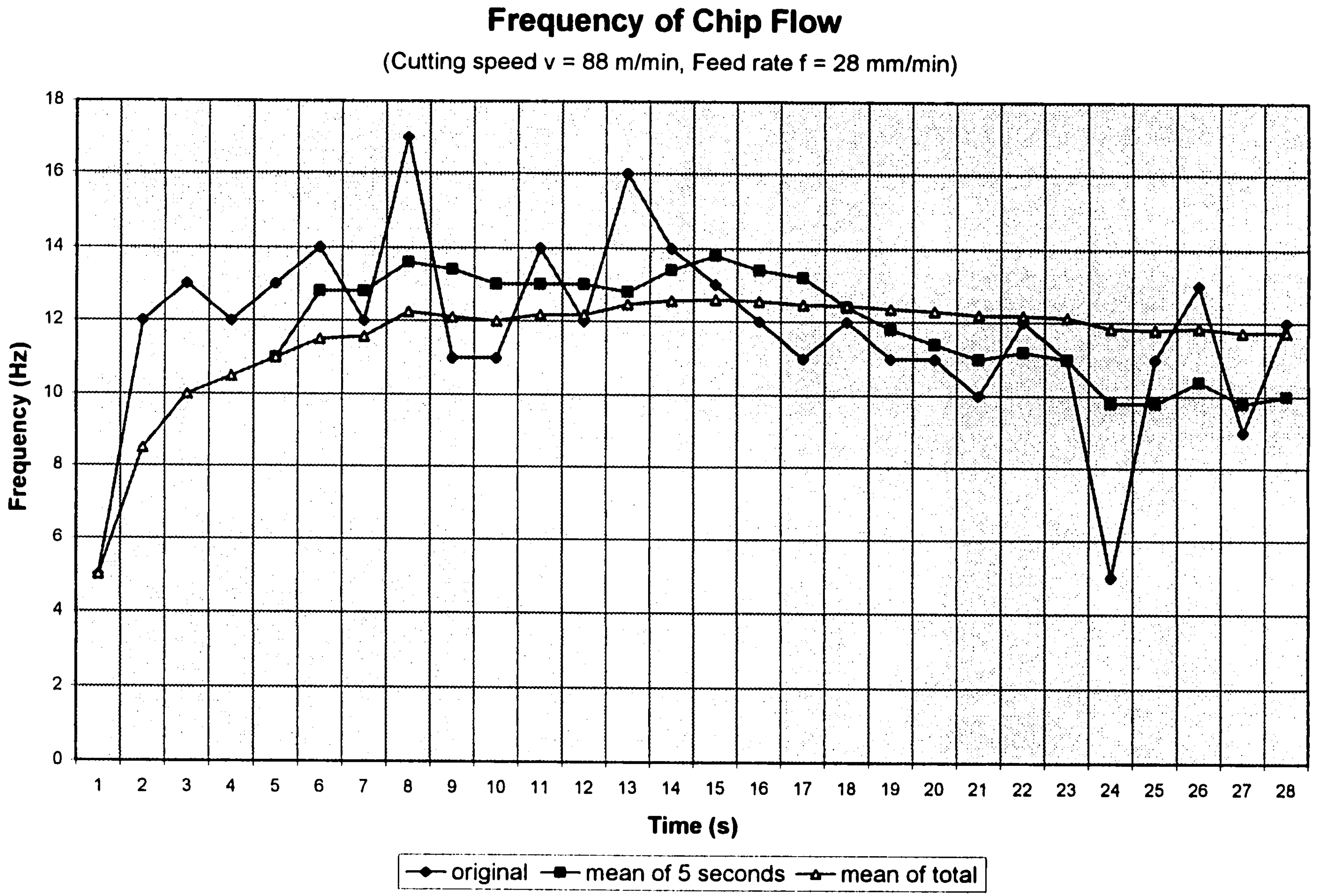
Chips' length distribution

Chips' length (mm)	%
40>Chips>30	21.3
>20	28
>15	17.3
<15	33.4

Graphics of chips length distribution



Sample of chips


Frequency of Chip Flow
(Cutting speed v = 88 m/min, Feed rate f = 28 mm/min)
Frequency (Hz)
0
2
4
6
8
10
12
14
16
18
Time (s)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
original
mean of 5 seconds
mean of total

Cutting speed v = 88 m/min, Feed rate f = 30.93 mm/min

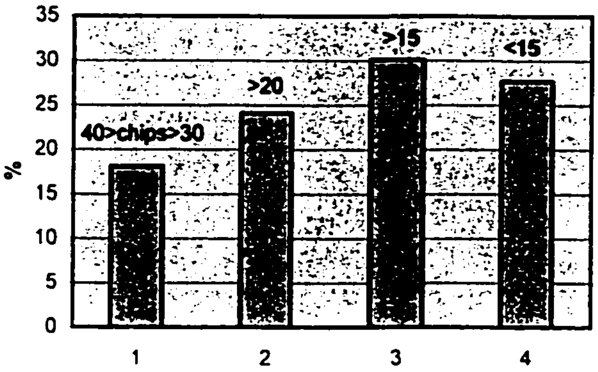
	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	12	12	12	
2	18	30	15	
3	14	44	14.66666667	
4	12	56	14	
5	15	71	14.2	14.2
6	11	82	13.66666667	14
7	13	95	13.57142857	13
8	16	111	13.875	13.4
9	9	120	13.33333333	12.8
10	20	140	14	13.8
11	16	156	14.18181818	14.8
12	13	169	14.08333333	14.8
13	16	185	14.23076923	14.8
14	15	200	14.28571429	16
15	12	212	14.13333333	14.4
16	16	228	14.25	14.4
17	10	238	14	13.8
18	2	240	13.33333333	11
19	9	249	13.10526316	9.8
20	17	266	13.3	10.8
21	13	279	13.28571429	10.2
22	16	295	13.40909091	11.4
23	15	310	13.47826087	14
24	17	327	13.625	15.6
25	13	340	13.6	14.8

1. Total mean of frequency: 13.6 Hz
2. Average length : 16.75 mm
3. 18.1% unacceptable
4. Unacceptbale

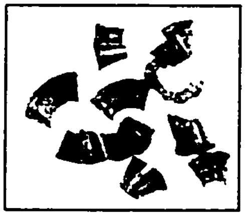
Chips' length distribution

Chips' length (mm)	%
40>Chips>30	18.1
>20	24.1
>15	30.1
<15	27.7

Graphic3 of chips length distribution

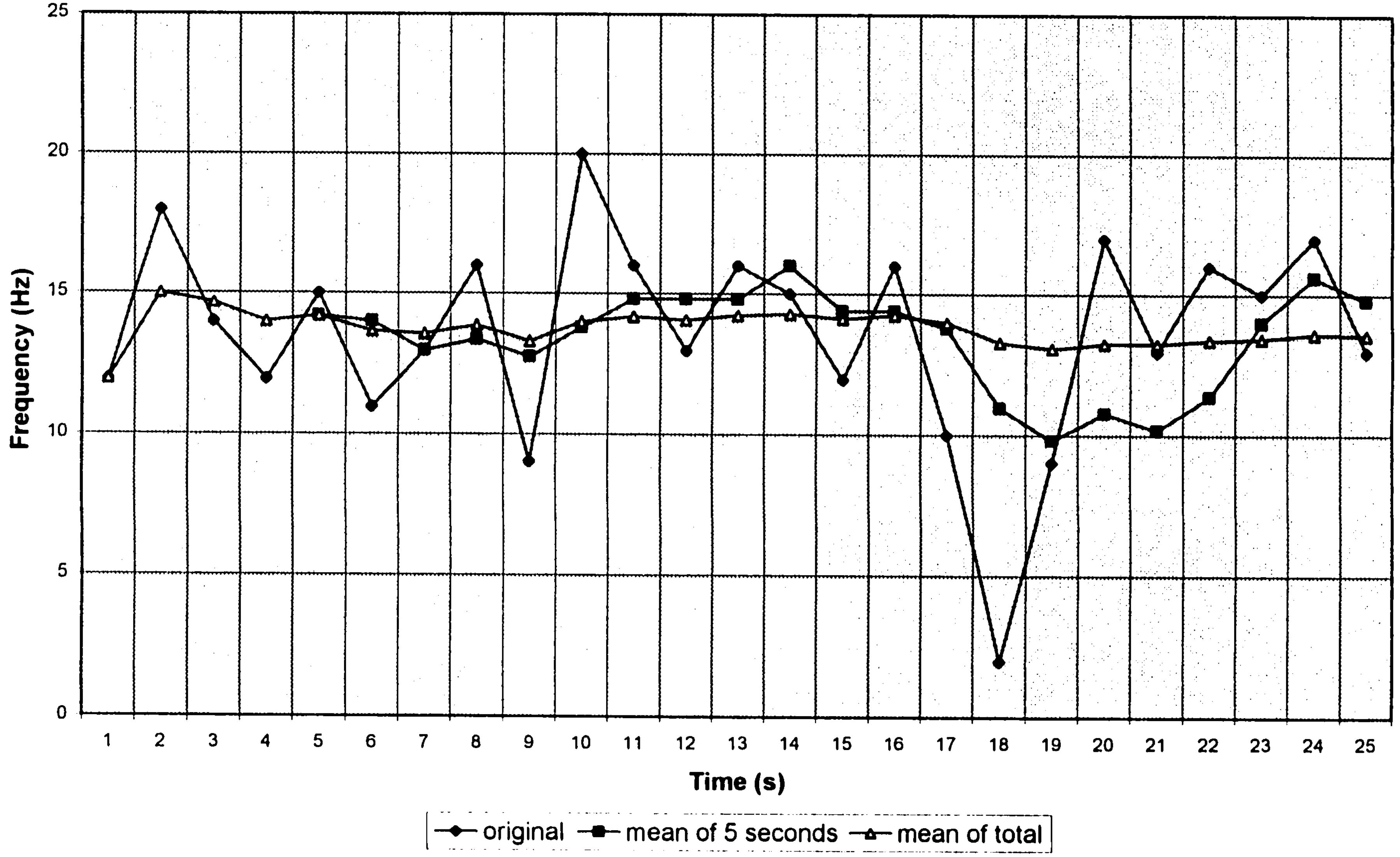


Sample of chips



Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 30.93 mm/min)



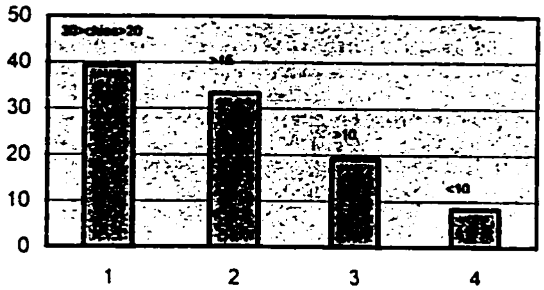
Cutting speed v = 88 m/min, Feed rate f = 33.78 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	14	14	14	
2	18	32	16	
3	14	46	15.33333333	
4	14	60	15	
5	13	73	14.6	14.6
6	9	82	13.66666667	13.6
7	9	91	13	11.8
8	16	107	13.375	12.2
9	13	120	13.33333333	12
10	16	136	13.6	12.6
11	13	149	13.54545455	13.4
12	8	157	13.08333333	13.2
13	11	168	12.92307692	12.2
14	12	180	12.85714286	12
15	15	195	13	11.8
16	8	203	12.6875	10.8
17	18	221	13	12.8
18	18	239	13.27777778	14.2
19	18	257	13.52631579	15.4
20	1	258	12.9	12.6

Chips' length distribution

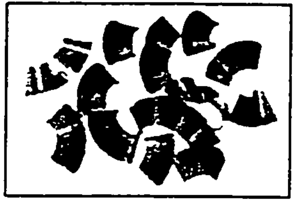
Chips' length (mm)	%
30>Chips>20	39.3
>15	33.3
>10	19.1
<10	8.3

Graphic of chips length distribution



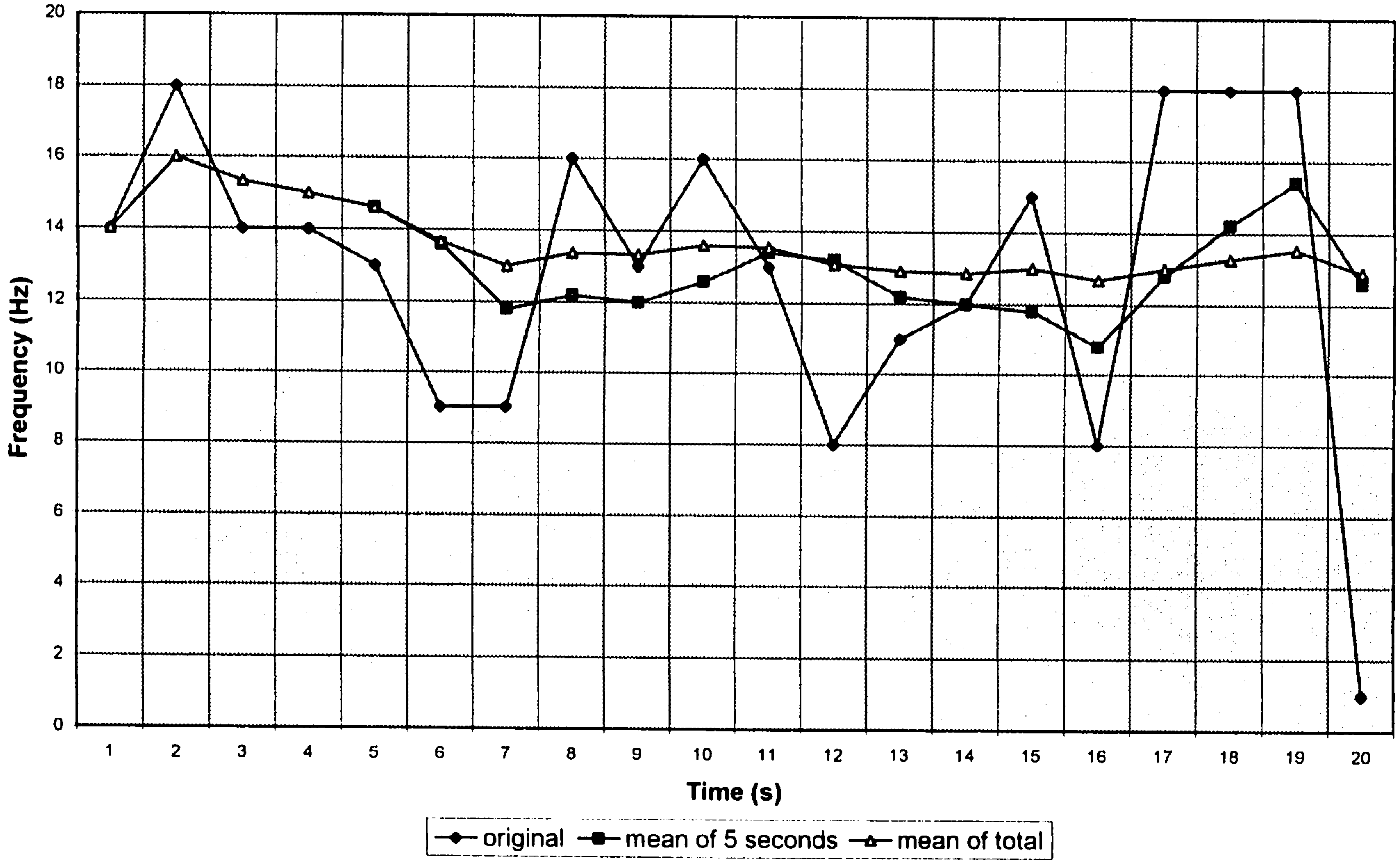
1. Total mean of frequency: 12.9 Hz
2. Average length : 15.59 mm
3. No unacceptable
4. Acceptbale, but not ideal

Sample of chips



Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 33.78 mm/min)



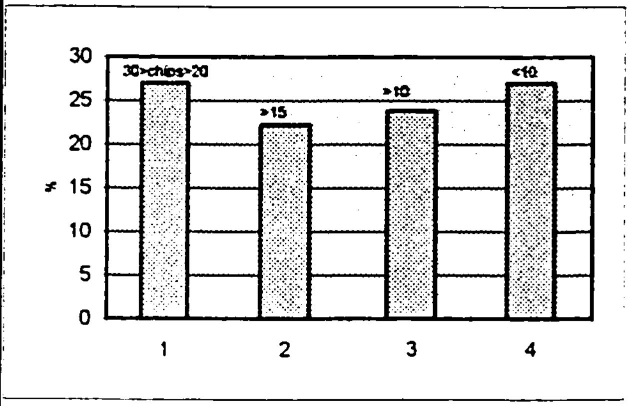
Cutting speed v = 88 m/min, Feed rate f = 36.8 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	21	21	21	
2	16	37	18.5	
3	4	41	13.66666667	
4	15	56	14	
5	14	70	14	14
6	15	85	14.16666667	12.8
7	0	85	12.14285714	9.6
8	15	100	12.5	11.8
9	18	118	13.11111111	12.4
10	15	133	13.3	12.6
11	10	143	13	11.6
12	13	156	13	14.2
13	17	173	13.30769231	14.6
14	17	190	13.57142857	14.4
15	20	210	14	15.4
16	11	221	13.8125	15.6
17	13	234	13.76470588	15.6
18	19	253	14.05555556	16
19	16	269	14.15789474	15.8
20	14	283	14.15	14.6
21	14	297	14.14285714	15.2
22	19	316	14.36363636	16.4
23	12	328	14.26086957	15
24	15	343	14.29166667	14.8
25	14	357	14.28	14.8
26	12	369	14.19230769	14.4
27	0	369	13.66666667	10.6
28	18	387	13.82142857	11.8
29	14	401	13.82758621	11.6
30	5	406	13.53333333	9.8
31	18	424	13.67741935	11
32	18	442	13.8125	14.6
33	6	448	13.57575758	12.2
34	16	464	13.64705882	12.6
35	13	477	13.62857143	14.2
36	15	492	13.66666667	13.6
37	19	511	13.81081081	13.8

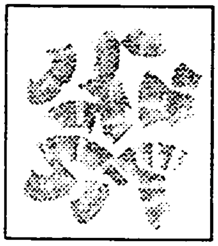
Chips' length distribution

Chips' length (mm)	%
30>Chips>20	27
>15	22.2
>10	23.8
<10	27

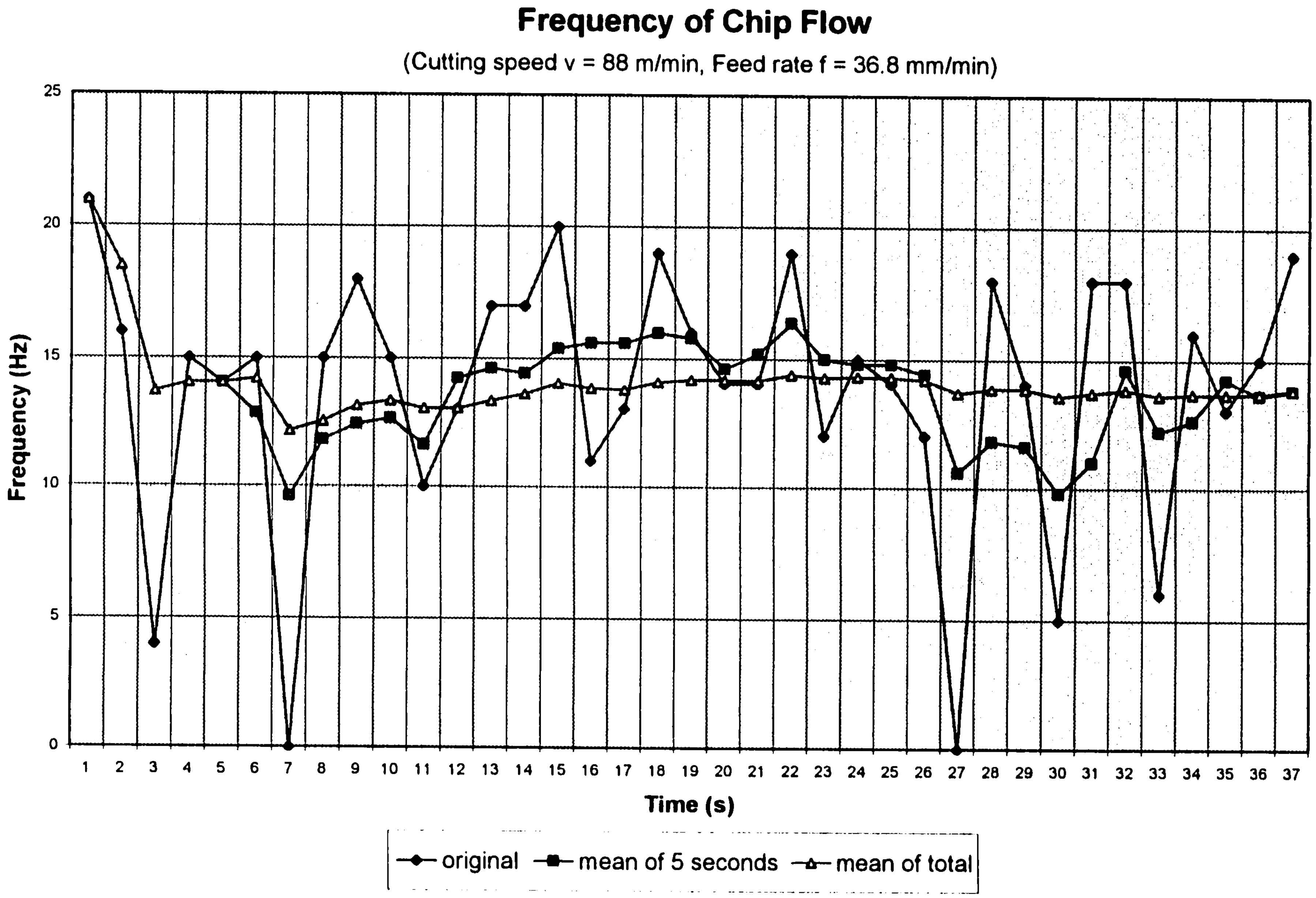
Graphics of chips length Distribution



Sample of chips



1. Total mean of frequency: 13.81 Hz
2. Average length : 13.81 mm
3. No unacceptable
4. Acceptbale, but not ideal



Frequency of Chip Flow

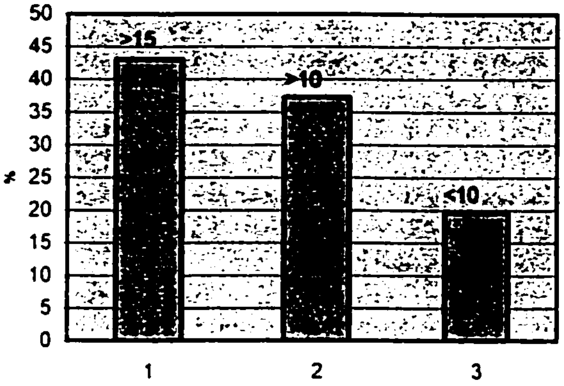
(Cutting speed v = 88 m/min, Feed rate f = 36.8 mm/min)

Cutting speed v = 88 m/min, Feed rate f = 39.73 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	13	13	13	
2	3	16	8	
3	20	36	12	
4	5	41	10.25	
5	15	56	11.2	11.2
6	16	72	12	11.8
7	14	86	12.28571429	14
8	16	102	12.75	13.2
9	18	120	13.33333333	15.8
10	18	138	13.8	16.4
11	16	154	14	16.4
12	1	155	12.91666667	13.8
13	10	165	12.69230769	12.6
14	19	184	13.14285714	12.8
15	24	208	13.86666667	14
16	12	220	13.75	13.2
17	18	238	14	16.6
18	19	257	14.27777778	18.4
19	21	278	14.63157895	18.8
20	20	298	14.9	18
21	17	315	15	19
22	13	328	14.90909091	18
23	1	329	14.30434783	14.4
24	13	342	14.25	12.8
25	11	353	14.12	11
26	4	357	13.73076923	8.4
27	14	371	13.74074074	8.6
28	20	391	13.96428571	12.4
29	10	401	13.82758621	11.8
30	18	419	13.96666667	13.2
31	14	433	13.96774194	15.2
32	3	436	13.625	13
33	10	446	13.51515152	11
34	13	459	13.5	11.6
35	14	473	13.51428571	10.8
36	13	486	13.5	10.6
37	11	497	13.43243243	12.2

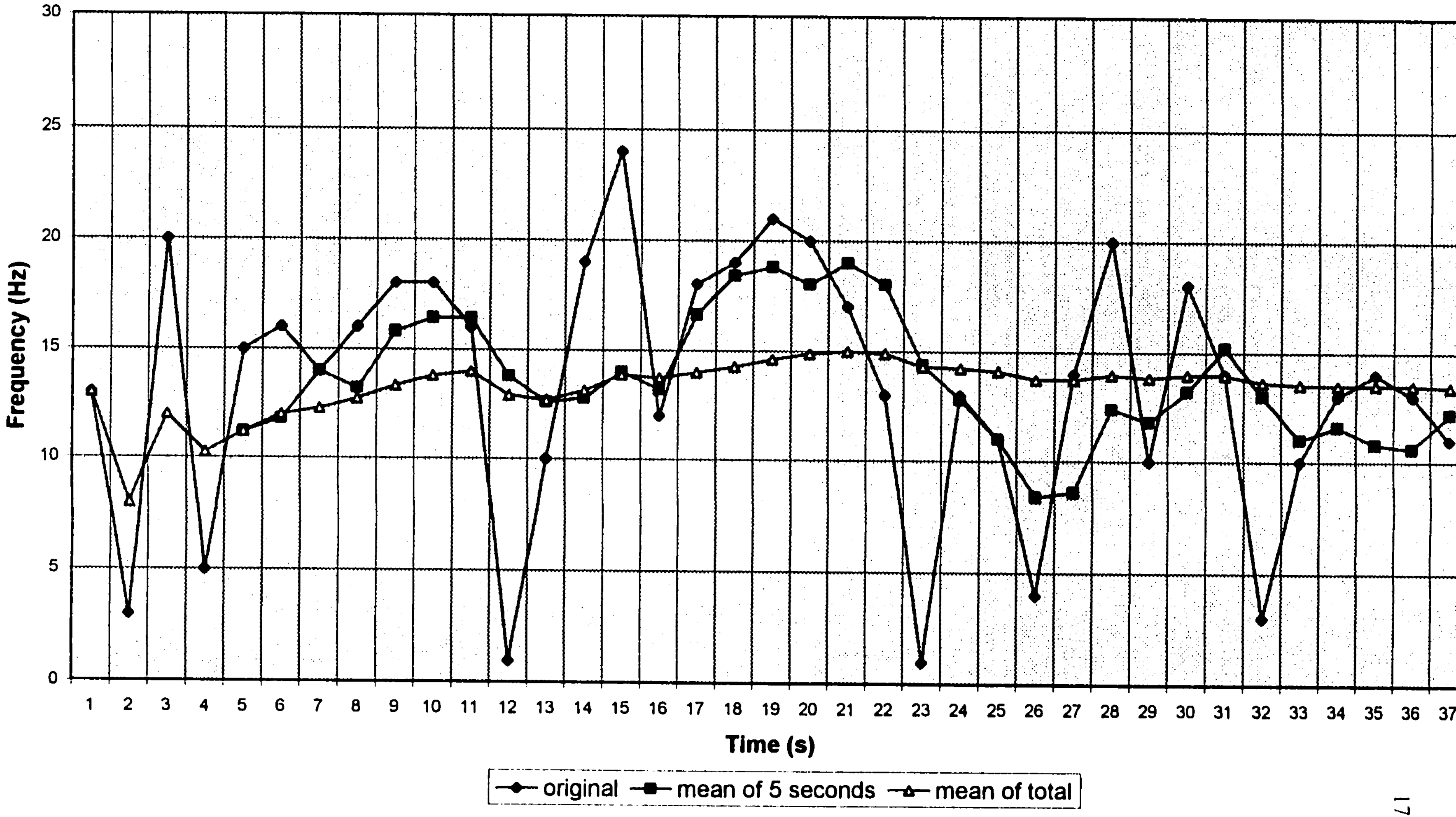
Chips' length distribution

Chips' length (mm)	%
20>Chips>15	43.1
>10	37.3
<10	19.6



Sample of chips

1. Total mean of frequency: 13.43 Hz
2. Average length : 12.16 mm
3. Acceptbale, but not ideal



Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 39.73 mm/min)

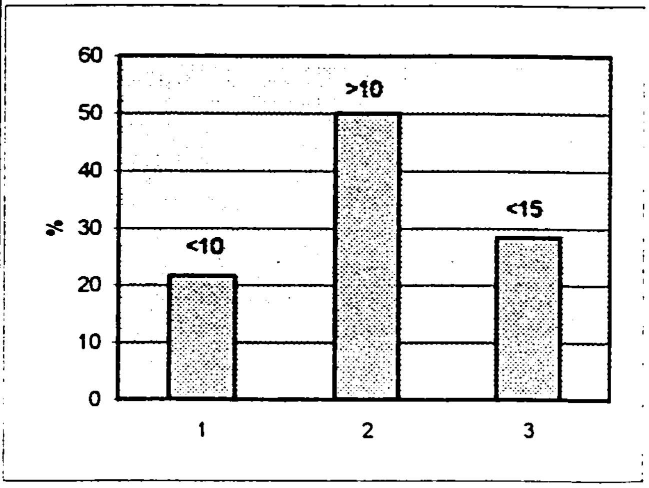
Cutting speed v = 88 m/min, Feed rate f = 42.67 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	15	15	15	
2	20	35	17.5	
3	13	48	16	
4	9	57	14.25	
5	17	74	14.8	14.8
6	15	89	14.8333333	14.8
7	6	95	13.5714286	12
8	18	113	14.125	13
9	13	126	14	13.8
10	1	127	12.7	10.6
11	12	139	12.6363636	10
12	20	159	13.25	12.8
13	17	176	13.5384615	12.6
14	23	199	14.2142857	14.6
15	11	210	14	16.6
16	17	227	14.1875	17.6
17	18	245	14.4117647	17.2
18	16	261	14.5	17
19	12	273	14.3684211	14.8
20	17	290	14.5	16
21	24	314	14.952381	17.4
22	17	331	15.0454545	17.2
23	20	351	15.2608696	18
24	16	367	15.2916667	18.8
25	12	379	15.16	17.8
26	18	397	15.2692308	16.6
27	16	413	15.2962963	16.4
28	11	424	15.1428571	14.6
29	18	442	15.2413793	15
30	16	458	15.2666667	15.8
31	17	475	15.3225806	15.6
32	11	486	15.1875	14.6
33	0	486	14.7272727	12.4
34	21	507	14.9117647	13
35	14	521	14.8857143	12.6
36	3	524	14.5555556	9.8

Chips' length distribution

Chips' length (mm)	%
20>Chips>15	21.6
>10	50
<10	28.4

Graphics of chips length distribution

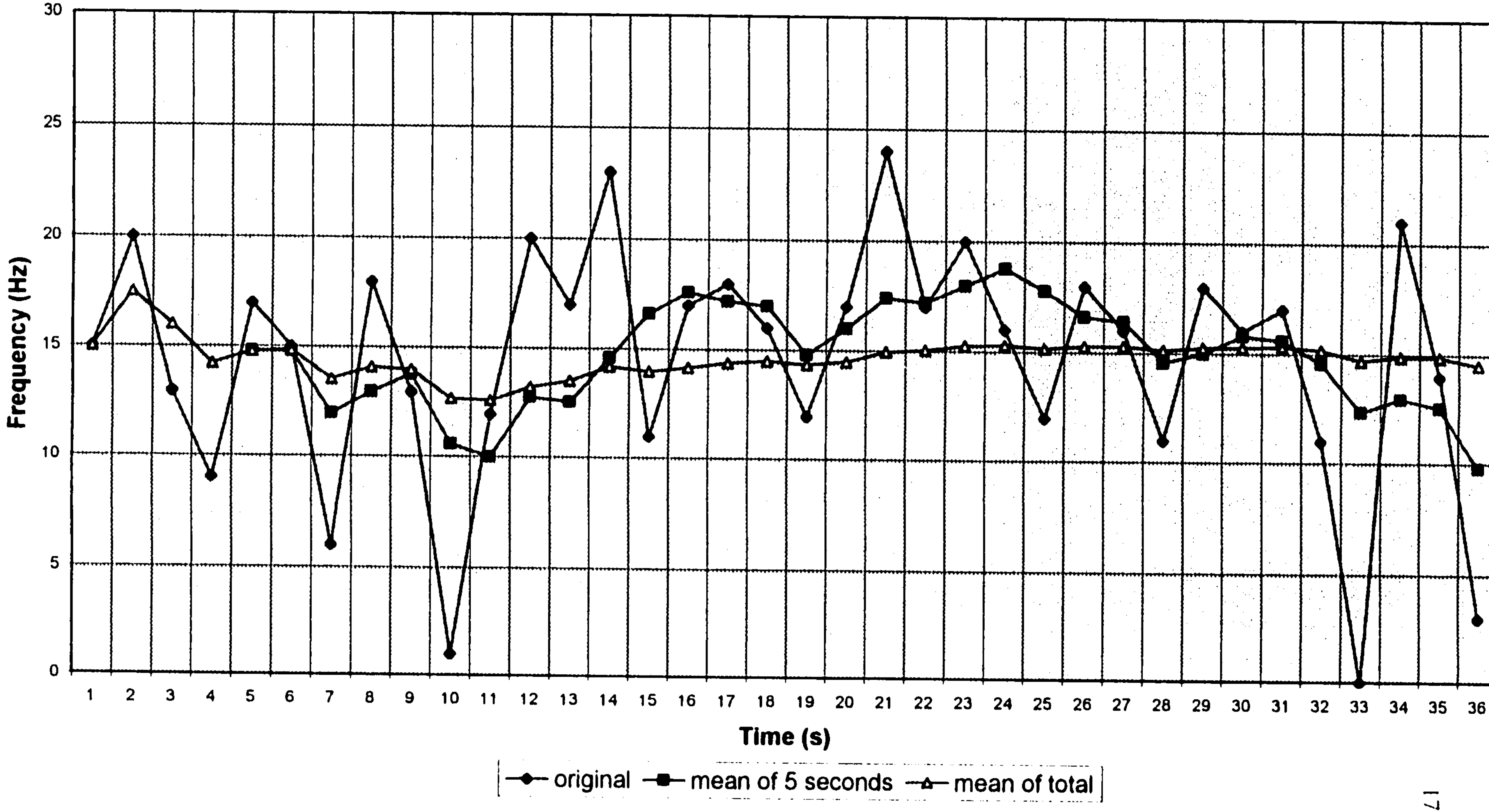


Sample of chips

1. Total mean of frequency: 14.56 Hz
2. Average length : 11.08 mm
3. Acceptbale, but not ideal

Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 42.67 mm/min)



Cutting speed v = 88 m/min, Feed rate f = 45.6 mm/min

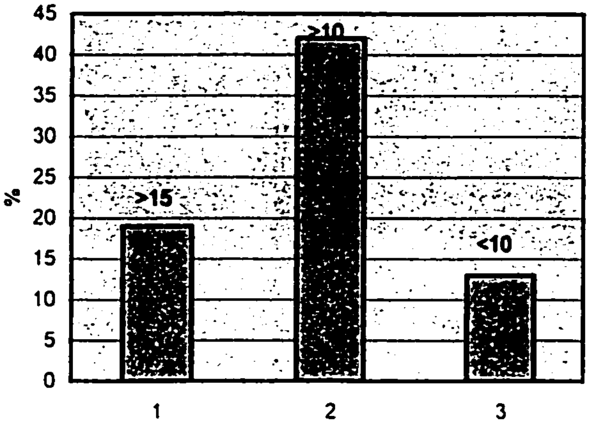
	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	18	18	18	
2	1	19	9.5	
3	24	43	14.33333333	
4	20	63	15.75	
5	20	83	16.6	16.6
6	14	97	16.16666667	15.8
7	5	102	14.57142857	16.6
8	13	115	14.375	14.4
9	18	133	14.77777778	14
10	12	145	14.5	12.4
11	19	164	14.90909091	13.4
12	22	186	15.5	16.8
13	18	204	15.69230769	17.8
14	13	217	15.5	16.8
15	20	237	15.8	18.4
16	22	259	16.1875	19
17	15	274	16.11764706	17.6
18	0	274	15.22222222	14
19	14	288	15.15789474	14.2
20	13	301	15.05	12.8
21	18	319	15.19047619	12
22	16	335	15.22727273	12.2
23	9	344	14.95652174	14
24	22	366	15.25	15.6
25	19	385	15.4	16.8
26	12	397	15.26923077	15.6
27	10	407	15.07407407	14.4
28	16	423	15.10714286	15.8
29	14	437	15.06896552	14.2
30	14	451	15.03333333	13.2
31	13	464	14.96774194	13.4
32	15	479	14.96875	14.4
33	6	485	14.6969697	12.4

1. Total mean of frequency: 14.7 Hz
2. Average length : 11.28 mm
3. Acceptbale, but not ideal

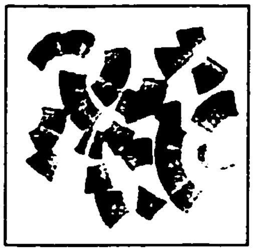
Chips' length distribution

Chips' length (mm)	%
>15	19
>10	42
<10	13

Graphics of chips length distribution

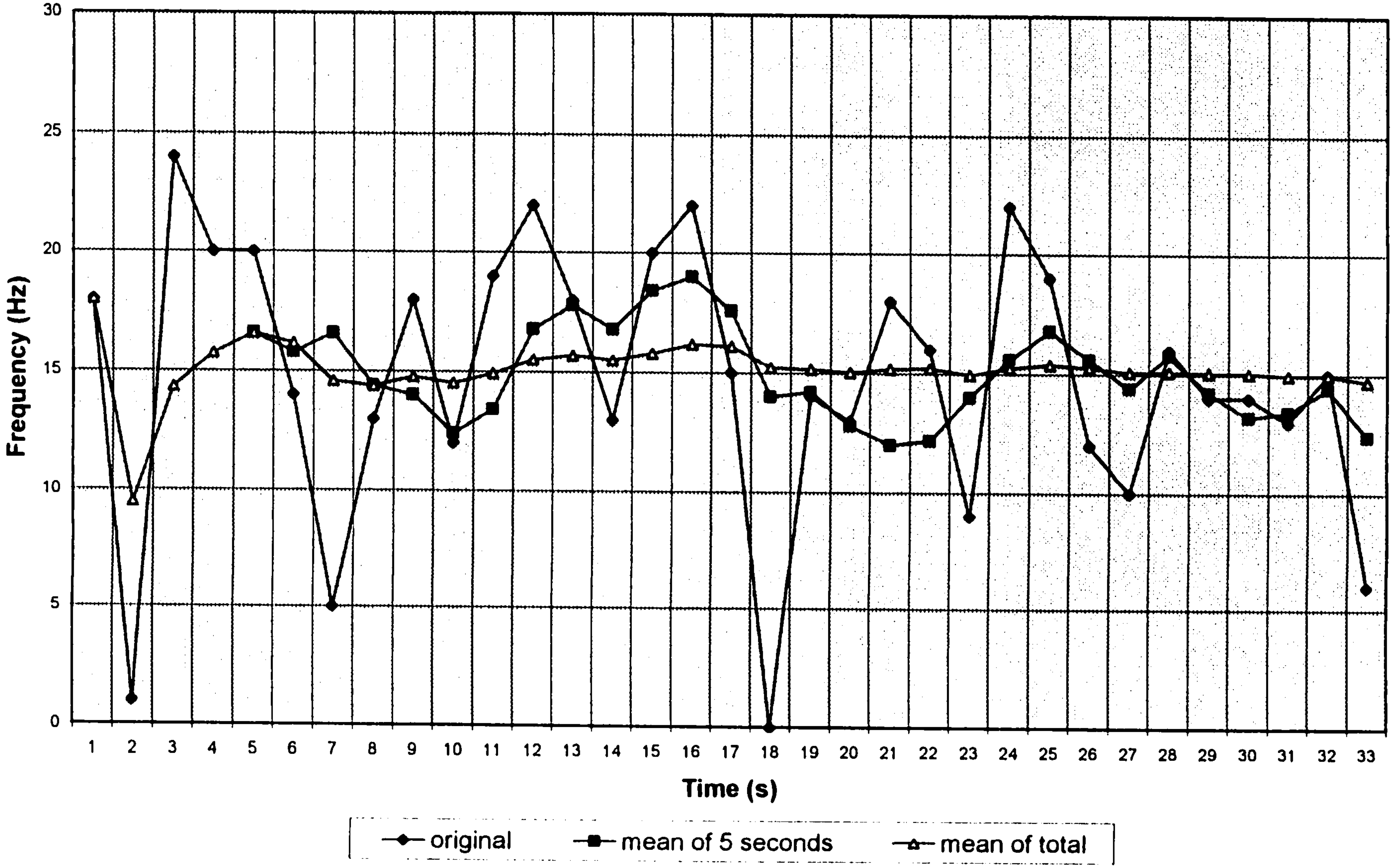


Sample of chips



Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 45.6 mm/min)



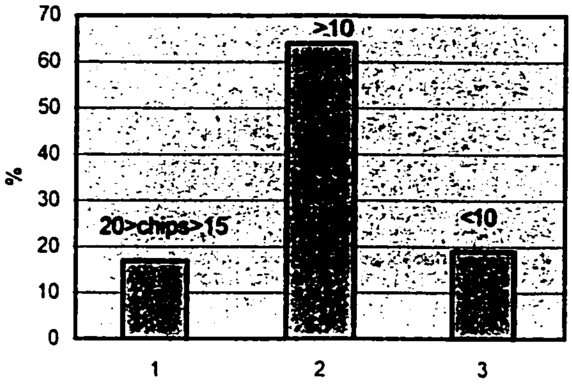
Cutting speed v = 88 m/min, Feed rate f = 48.53 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	15	15	15	
2	20	35	17.5	
3	23	58	19.33333333	
4	22	80	20	
5	15	95	19	19
6	17	112	18.66666667	19.4
7	4	116	16.57142857	16.2
8	24	140	17.5	16.4
9	5	145	16.11111111	13
10	19	164	16.4	13.8
11	19	183	16.63636364	14.2
12	0	183	15.25	13.4
13	18	201	15.46153846	12.2
14	10	211	15.07142857	13.2
15	20	231	15.4	13.4
16	18	249	15.5625	13.2
17	15	264	15.52941176	16.2
18	17	281	15.61111111	16
19	10	291	15.31578947	16
20	20	311	15.55	16
21	17	328	15.61904762	15.8
22	17	345	15.68181818	16.2
23	7	352	15.30434783	14.2
24	6	358	14.91666667	13.4
25	23	381	15.24	14
26	23	404	15.53846154	15.2
27	0	404	14.96296296	11.8
28	14	418	14.92857143	13.2
29	20	438	15.10344828	16
30	18	456	15.2	15
31	6	462	14.90322581	11.6

Chips' length distribution

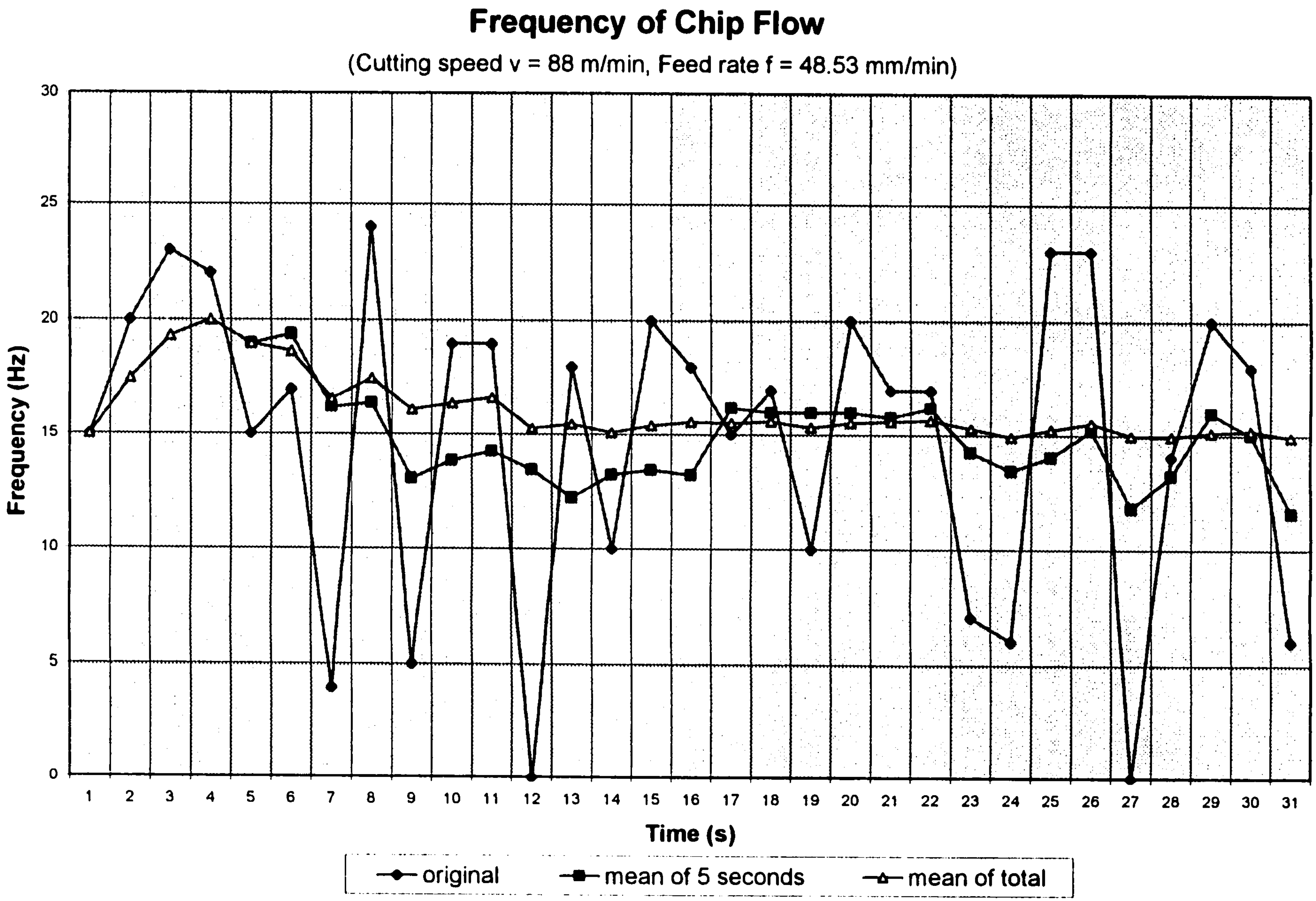
Chips' length (mm)	%
20>Chips>15	17
>10	64
<10	19

Graphics of chips length distribution



Sample of chips

1. Total mean of frequency: 14.9 Hz
2. Average length : 10.85 mm
3. Acceptbale, but not ideal


Frequency of Chip Flow
(Cutting speed v = 88 m/min, Feed rate f = 48.53 mm/min)
Frequency (Hz)
30
25
20
15
10
5
0
Time (s)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
original
mean of 5 seconds
mean of total

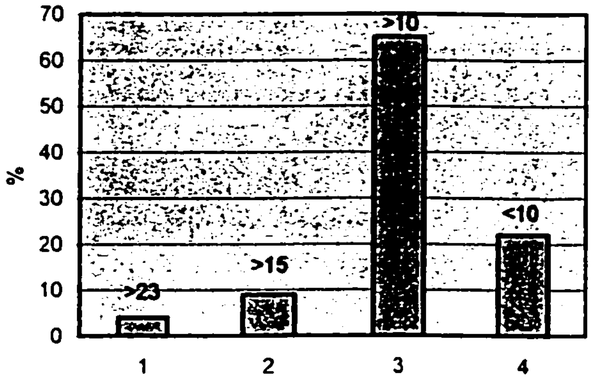
Cutting speed v = 88 m/min, Feed rate f = 50.29 mm/min

	frequency (Hz)			
time (s)	original	sum	mean of total	mean of 5 seconds
1	12	12	12	
2	10	22	11	
3	21	43	14.33333333	
4	20	63	15.75	
5	18	81	16.2	16.2
6	21	102	17	18
7	23	125	17.85714286	20.6
8	14	139	17.375	19.2
9	13	152	16.88888889	17.8
10	17	169	16.9	17.6
11	17	186	16.90909091	16.8
12	1	187	15.58333333	12.4
13	18	205	15.76923077	13.2
14	21	226	16.14285714	14.8
15	16	242	16.13333333	14.6
16	22	264	16.5	15.6
17	17	281	16.52941176	18.8
18	21	302	16.77777778	19.4
19	27	329	17.31578947	20.6
20	8	337	16.85	19
21	23	360	17.14285714	19.2
22	31	391	17.77272727	22
23	18	409	17.7826087	21.4
24	17	426	17.75	19.4
25	15	441	17.64	20.8
26	18	459	17.65384615	19.8
27	22	481	17.81481481	18
28	22	503	17.96428571	18.8
29	5	508	17.51724138	16.4
30	20	528	17.6	17.4
31	16	544	17.5483871	17

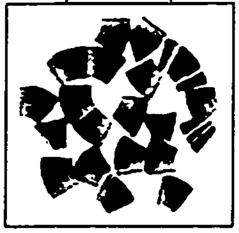
Chips' length distribution

Chips' length (mm)	%
>23	4
>15	9
>10	65
<10	22

Graphics of chips length distribution



Sample of chips



Frequency of Chip Flow

(Cutting speed v = 88 m/min, Feed rate f = 50.29 mm/min)