1

General Notions About the Introduction of Technical Diagnosis for Machine Tools

1.1 INTRODUCTION: THE PLACE AND THE ROLE OF DIAGNOSIS IN MODERN TECHNICAL SYSTEMS

The diagnosis of technical systems can be defined as a process of functional faults and their causes, on the basis of data obtained by control, supervising, or monitoring. The rudiments of establishing technical diagnosis have been present for a long time regarding the estimation of the functioning state of a machine or equipment. Thus, it was natural that the functioning anomalies be noticed by the operator of the machine, such as: modifications of level or type of emitted noise, too much energy consumed, low output, the vibration level increasing, or local or global excessive heating. On the basis of these observations the operator could intervene to correct the deficiencies or to decide to stop the machine.

Even by this subjective elementary diagnosis method, some important advantages could be identified:

Increased sensorial accuracy of the operators
Enhanced "database" of the operator's memory, built upon accumulated experiences

The possibility to control, analyze, diagnose, and intervene during the machine's functioning, before reaching the faults

Objective diagnosis, on the basis of some precise techniques and methods, has been propelled during the last decade by two important factors: the large scale introduction of automated production processes, and the development of data acquisition, measuring, and signal processing equipment. In these conditions, it becomes necessary to use some supervisory/control systems to ensure machine reliability.

What is the role of such systems? In short it can be described as:

To supervise the functioning state of the production system to prescribed performances

To reduce and even avoid accidental breaks in functioning by supervising some significant factors during the technological process

To avoid the limit situations, which can generate faults and damages

To reduce, even eliminate, fabrication waste by supervising every step in the evolution of the product, parallel with the reduction of materials consumption

To analyze functioning state tendencies, locally or globally, in order to plan interventions

The supervising/diagnosing system for the technological process may be identified as an auxiliary system that has the possibility of being integrated in a reaction buckle.

The signal, from a mechanical, pneumatic, acoustic, thermic, or such nature, is captured by adequate sensors and then converted to electrical signals, and sent to a postprocessing block (Figure 1.1). The white noise and the parasite signals are eliminated here; and the characteristic parameters of the supervised signal are extracted. Interpreting these signals on the basis of adequate software, the supervising/diagnosis block, which is the ensemble of electronic devices, offers data for fault recognition and their causes, and identification of where and when the fault arises. Depending upon the integrating degree of the supervising/diagnosing system, the reaction buckle can be:

Half-closed (warning/alarming reaction; stopping of the technological process) or

Closed (continuing the data acquisition, concentrating on the element predisposed to fault, with the beginning of some testing procedures; the modification of some parameters of the tech-

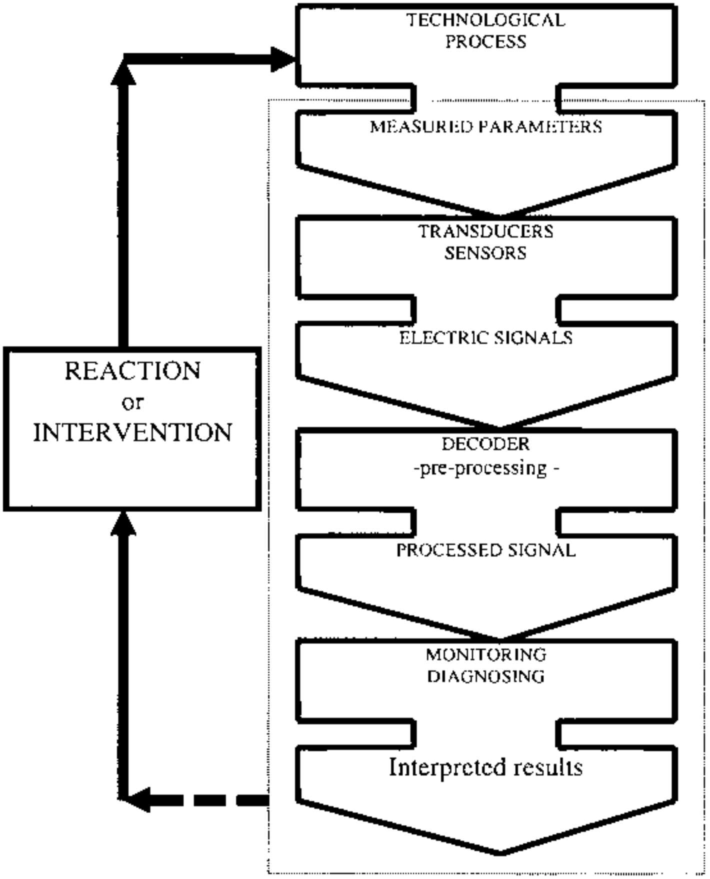


FIGURE 1.1 Preprocessing block.

nological process to improve the functioning state; warning the experts and stopping the process to the limit)

1.2 MONITORING, THE FIRST STEP IN ESTABLISHING THE TECHNICAL DIAGNOSTIC

Monitoring is defined as the activity of gathering information about the functioning state in a given system, by means of adequate observation of instruments and measuring apparatus in order to supervise and intervene for correction purposes. The axiom of maintenance by monitoring is that the intervention maintenance/repairing is done only when the measurements show its necessity (Figure 1.2).

The monitoring technical system can have two functions:

The protection or preventive function, which imposes a warning or automatically stops the equipment if it senses the possibility of a fault

The analysis and prediction function, which selects the main state modifications and surveys their evolution; the system expert will provide efficient solutions for remedy before any final damage

Preventive monitoring is recommended for machines that are not integrally doubled or where unplanned interruption would lead to large production loss. In this case, the monitoring is directed to those components whose failure (in a shorter time than estimated) would have serious consequences for the entire assemblage.

Predictive monitoring is mainly oriented to those machines and equipment with a continuous technological flux, and which might have accidental stops or revision/repairing periods implying considerable production loss; it is also oriented to complex production systems where the damage of a subsystem would block the entire flux. In this case, the

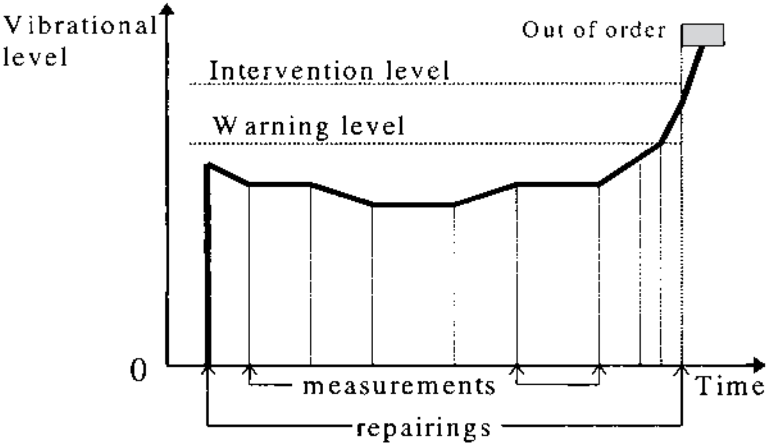


FIGURE 1.2 Levels of necessary intervention.

functioning state is intermittently or continuously supervised until the modification of the supervised parameters is able to signal imminent or predictable spoiling, and then take the imposed measures.

The stages that have to be crossed to build the monitoring schema are as follows.

1. Make schematic descriptions of the machine, equipment, or installation, divided on technological subassemblies and groups, from the functional and constructive point of view.
2. Make schematic descriptions of each component, marking the controlled elements and the monitored control points. An adequate monitoring for the fixed control points and for arranging and retaining the recordings should be used. The number of control points depends on the system complexity and on the spoilage consequences. This number will determine the complexity of the monitoring schema and also the number of qualified personnel required for analyzing and supervising.
3. The conceived monitoring schema will be implemented into the system and will provide information concerning the system functioning state. Based upon this information, graphics can be drawn manually or automatically which will show the evolution of the studied parameters, and indicate the values considered normal. Preliminary diagnostics can be established, and preventive repairing can be planned. Previous special events, faults, and other evaluation criteria, in short, “the machine history,” can be added to these data by adequate description.

1.3 APPLICATION OF VIBROACOUSTIC DIAGNOSIS TO MACHINE TOOLS

Modern machine tools are dynamic complex assemblies composed of mechanical subsystems (gears, bearings, cam mechanisms, couplings, belt transmissions), hydraulic equipment (pumps and hydraulic engines, distribution equipment, etc.), and electric equipment (motors, contactors, etc.). Because of this structural complexity, it is very difficult to establish technical diagnostics for machine tools. From the same point of view, the diagnosis of the cutting tools is much simpler and much of the present research is oriented in this domain.

1.3.1 Sources of Machine Tool Vibration and Noise

Not only the functioning of subsystems and subsystems of the machine tool but also the cutting process generates vibration and noise. A rapid way to identify the sources of this phenomenon, which might generate damage, is represented by the connection (gradual, separate, or in diverse combinations) of the functional elements of the machine (electrical motors, transmissions, main kinematic chain, feed kinematic chains, lubricating system, etc.), by analyzing each time the vibrograms result in the measurement points. Figure 1.3 presents the internal and external vibration and noise sources that determine the vibroacoustic behavior of the machine tools [76].

1.3.1.1 Free Vibrations

The free vibrations appear in the absence of some perturbing forces, as components of some transitory processes of the machine tool. These processes and vibrations have a relatively short duration, as the vibrations imply.

Free vibrations develop with the self-frequency of the elastic systems where they were born, and this phenomenon is interesting from the point of view that the generating transitory systems can determine or influence the dynamic behavior of the machine tool. Considering this, some important transitory processes can be mentioned.

The on/off chip contact of the tool leads to deformation variations of the elastic fixing system in a transitory process whose duration surpasses the time of a complete rotation of the main shaft; this sometimes happens during the entire passage. Analysis of this process has established an exponential law of variation of the y deformation of the elastic system:

$$y = a_o \exp\left(\frac{t}{\frac{\tau}{2}(1 + 2R_{SE}K_a)}\right) \tag{1.1}$$

where a_o is the nominal thickness of the cutting layer, t is the time, τ is the duration of a rotation or technological cycle, and R_{SE}, K_a are the static characteristics of the elastic system and cutting process. It must be noted that the numerator of the exponent represents the time constant T of the technological process. Generally its duration is appreciated to be $t = (3 \ldots 5)T$.

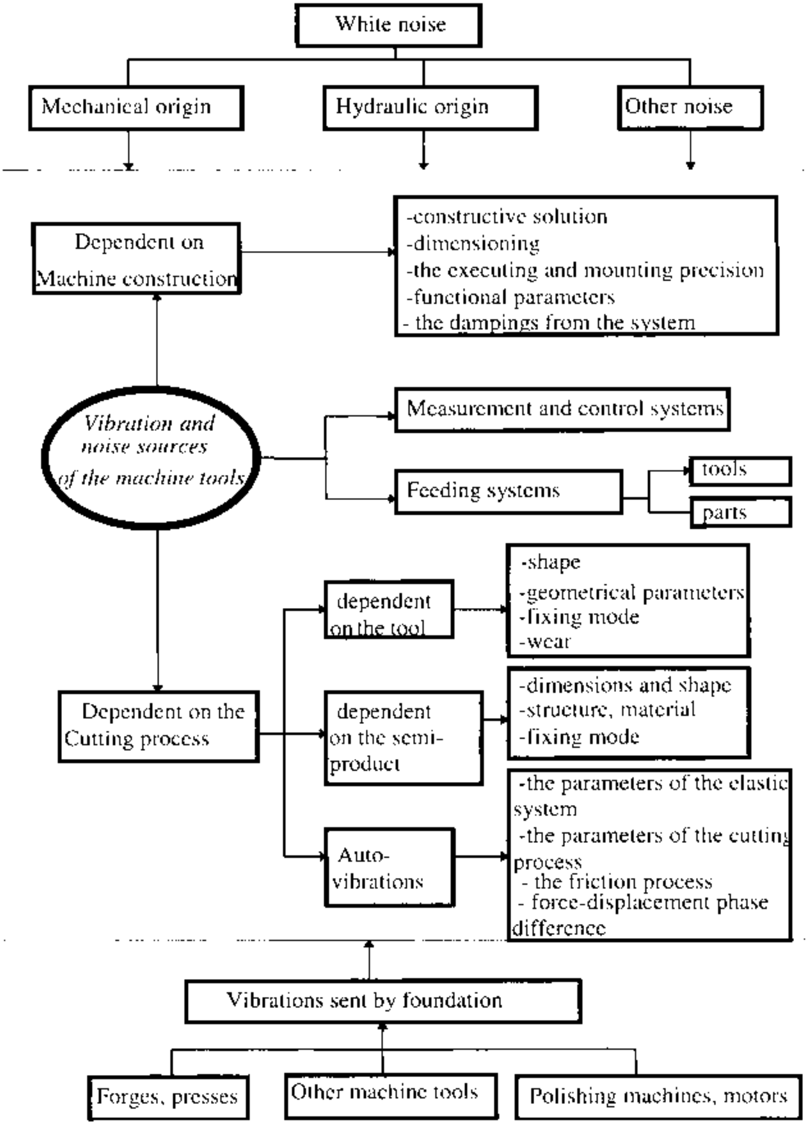


FIGURE 1.3 Internal and external vibration and noise sources that determine the vibroacoustic behavior of the machine tools.

Accelerating/breaking of the mobile elements appears when the still state or the uniform movement of some mobile subassemblages is changed, such as tables, sledges, supports, and traverses. The developing law of these processes is also exponential, similar to that previously presented. The experimental results have established the value of the time constant of this process at 0.3 to 1 sec, so the transitory process could take maximum 5 sec.

Inverting the direction of movement is a more complicated process, consisting of three phases: breaking the movement, stopping, and restarting in a new direction. This process is accompanied by a series of complex dynamic phenomena: shocks, changing the direction of the friction forces, the modification of the pressure repartition on the guiding, abrupt temperature variations in the kinematic couple, and so on. Also taking into consideration the presence of the plays from the kinematic couplings, it can be shown that changing the direction of movement is a random process with unfavorable consequences for the dynamic of the machine tools. The greater the number of masses in movement, the greater are the consequences.

The study of machine tool free vibrations is important because the dynamic parameters of the elastic systems that compose them are determined with the help of linear differentially homogeneous equations which describe the free vibrations of these systems.

1.3.1.2 Autovibrations

The autovibrations are kept-up vibrations, caused by excitation factors generated from the vibration movement. These can be as follows.

1. The interdependence between the magnitude of the cutting force and the relative displacement between the tool and semiproduct: due to an external cause, the cutting force varies, making a resultant mechanical work positive per variation cycle, and the energy resulting from this keeps up the vibration process. The rise of autovibrations depends upon the values and the ratio of the rigidities from the elastic system, and also upon the position of the main rigidity directions, while the frequency of the autovibrator process is very close to the self-frequency of the elastic system, without being equal to it. Figures 1.4a, b, c illustrate the influence of the cutting process parameters (respectively v, s, t) over the

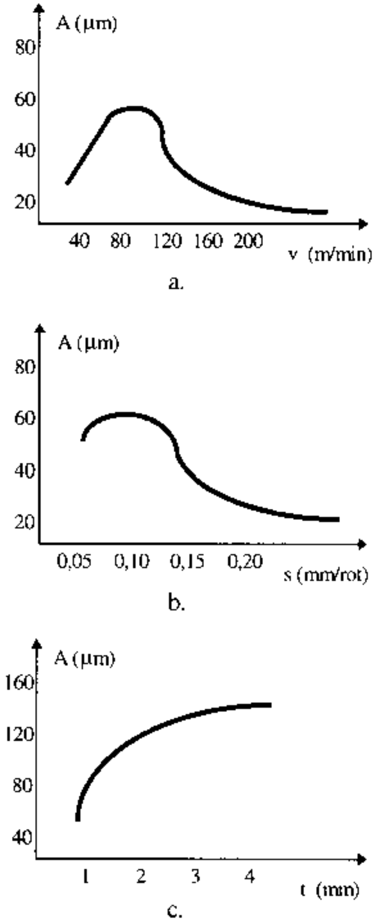


FIGURE 1.4 Influence of cutting process parameters (respectively, v, s, t) over the autovibrations amplitude.

autovibration amplitude. It can be observed that the cutting depth has a very powerful influence on the autovibrational process and is able to raise the vibration amplitude to 140 μm. The depth of cut (when the stability of the elastic system to vibrations is surpassed), is called critical depth, and it is adopted as a parameter for evaluation of the vibration stability of the elastic system of the machine tools.

2. The dependence between the friction force and the sliding speed from the kinematic couples: the autovibrations of this process manifest as jerky motions that appear with the movement of the mobile assemblies with speeds under a specific critical value. This phenomena is known as stick-slip. These autovibrations, also called "of relaxation," can be attenuated by an adequate selection of the couple of materials, rational lubrication, and discharging of the contact surfaces.

3. The phase difference between the variation of the cutting force and move away: this autovibration type highlights the copying kinematic chains. Their occurrence is favored by the presence in the elastic system of the nonlinearity of playing type, hysteresis, and instabilities. The frequency of these vibrations is approximately equal to the self-frequency of the excited elastic system.

4. The regenerative vibrations appear due to the existence of surface waves that were manufactured at the previous pass and which, at a new pass, generate dynamic forces conditioned by the intensity of the dependence between the variation of the chip depth and the cutting force. The effect of regenerating vibrations then has the proportional variation of the autovibration frequency function of the main shaft or tool rotation.

A characteristic aspect of autovibrations consists of the possibility of raising the amplitudes in time that lead to the trepidation occurrence, which is a very dangerous phenomenon.

Concerning noise and acoustical emission, the machine tools cover a very large domain:

Infrasounds (vibrations with a frequency lower then 16 Hz) due to structural dislocations, phase transforming, and the like

Sounds (the audible domain: 16–20,000 Hz) due to the functioning of diverse types of mechanisms that compose the kinematic chains and are grouped in low sounds (16–360 Hz), medium sounds (360–1400 Hz), and high sounds (1400–20,000 Hz)

Ultrasounds (vibrations having their frequency higher then 20 kHz) due to the increasing occurrence of crackings, microfrictions on the level of cracked surfaces, microcollisions with and between the microscopic particles, and so on

Noise measurement allows us to estimate the "silence" of the machine tools when running out of job, from the point of view of the technical criteria of execution and operator protection. It permits us to establish if the level of maximum noise produced by a machine tool is within the admitted limits imposed by the standards. This also allows us to locate the machine elements that produce high-level noise and to make a comparison between the noise levels produced by the same type of machines.

The machine tool whose noise level is measured has to be completely equipped (with all the covers and guards), adjusted for proper functioning, and run in and installed on a basis plate under the same conditions that it is installed for exploitation. The noise level is measured when the machine is idle-running with the usual rotations and advances.

The measurement points are disposed on a measurement line whose trace in the horizontal plane is situated at a height of 1.5 m from the basis plane, and at a distance of 1 m from the contour line of the machine tool. The nonnoisy prominences are not taken into consideration. For each type of machine tool, the location of the measuring points is established in a concrete way. Their minimum number is four, and other supplementary points can be chosen as a function of the machine tool sizes. The placement of the measuring points for different types of machine tools is shown in Figures 1.5a to k, and the admissible values of the noise levels for these machines are presented in Table 1.1 [64, 149, 150].

Acoustical emission is a succession of high frequency elastic waves (>100 kHz), generated by freeing the internal energy stored in a structure. It allows detection of fissures and/or ruptures. When the cutting process is running on the machine tools, the sources of acoustical emission are numerous: continuous or discontinuous chip forming, processed material deformation, fissuring of the semiproduct or the tool, friction among the tool, semiproduct, chip breaker, fracture, and collision of the chip. In addition to all of the above, other sources of acoustical emission come from the functioning of some mechanical subassemblies (gear wheels, bearings) and high-frequency electrical sources.

1.3.2 Requirements for Machine Tool Diagnostic Systems

Utilization of the diagnostic systems should correspond with the importance of the supervised system of the production system, with its complexity, and with its performance. Usually the monitoring is oriented to numerical command machine tools, processing centers, cells, flexible processing lines, and also to cutting tools.

Machine type	Turn rpm	0 - 500		500 - 1000		1000 - 2000		2000 - 4000		4000 - 8000		8000 - 16000	
	The power kW	L dB (A)	Çz	L dB (A)	Çz	L dB (A)	Çz	L dB (A)	Çz	L dB (A)	Çz	L dB (A)	Çz
Grinding machines	1.0-1.6	-	-	-	-	-	-	-	-	80	75	83	80
	2.5-4.0	-	-	75	70	78	75	81	75	-	-	-	-
	4.0-6.3	-	-	77	70	80	75	83	80	-	-	-	-
	6.3-10.0	-	-	77	70	80	75	83	80	-	-	-	-
Shaping machines	1.6-2.5	75	70	-	-	-	-	-	-	-	-	-	-
	2.5-4.0	80	75	-	-	-	-	-	-	-	-	-	-
	4.0-6.3	82	80	-	-	-	-	-	-	-	-	-	-
	6.3-10.0	85	80	-	-	-	-	-	-	-	-	-	-
Portal milling machines	10.0-16.0	79	75	82	80	85	80	-	-	-	-	-	-
	16.0-25.0	81	80	84	80	87	80	-	-	-	-	-	-
	25.0-40.0	83	80	86	80	89	85	-	-	-	-	-	-
Reaming and milling machines	6.3-10.0	-	-	79	75	82	80	85	80	-	-	-	-
	10.0-16.0	-	-	82	80	85	80	88	85	-	-	-	-
	16.0-25.0	-	-	84	80	87	80	90	85	-	-	-	-
Vertical and universal milling machines	1.6-2.5	-	-	75	70	78	75	81	80	75	-	-	-
	2.5-4.0	-	-	77	70	80	75	83	80	-	-	-	-
	4.0-6.3	-	-	79	75	82	80	85	80	-	-	-	-
	6.3-10.0	-	-	82	80	85	80	87	80	-	-	-	-
	10.0-16.0	-	-	-	-	87	80	-	-	-	-	-	-
Boring machines	1.0-1.6	-	-	-	-	75	70	78	75	80	75	-	-
	1.6-2.5	-	-	-	-	76	70	79	75	80	80	-	-
	2.5-4.0	-	-	75	70	78	75	81	75	-	-	-	-
	4.0-6.3	-	-	77	70	80	75	83	80	-	-	-	-
Normal and revolver lathes	1.6-2.5	-	-	-	-	77	70	70	75	85	80	-	-
	2.5-4.0	-	-	-	-	79	75	82	80	85	80	-	-
	4.0-6.3	-	-	-	-	81	75	84	80	90	80	-	-
	6.3-10.0	-	-	-	-	83	80	86	80	90	85	-	-
	10.0-16.0	-	-	-	-	85	80	88	85	-	-	-	-

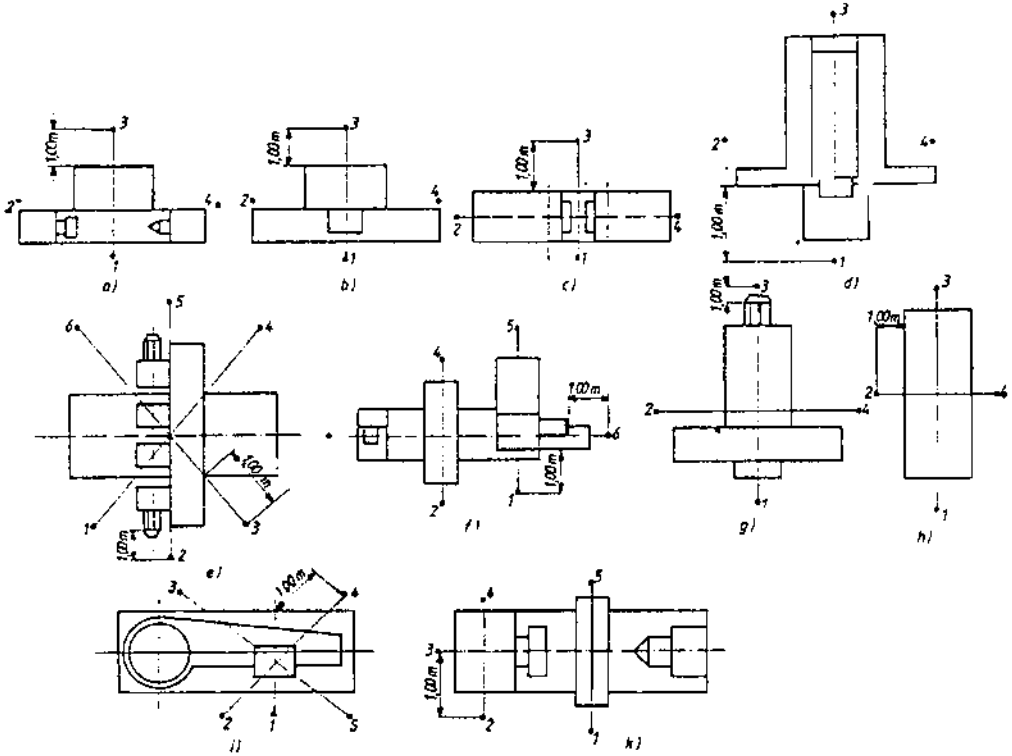


FIGURE 1.5 Placement of the measuring points on different types of machine tools: (a) universal grinding machine; (b) surface grinding machine; (c) centerless grinding machine; (d) shaping machine; (e) portal milling machine; (f) reaming and milling machine; (g) vertical milling machine; (h) radial boring machine; (i) boring machine with column; (k) normal and revolver lathes.

TABLE 1.1 Admissible Values of the Noise Level for Different Types of Machine Tools

Machine type	Turn rpm power kW	0–500		500–1000		1000–2000		2000–4000		4000–8000		8000–16000	
		L dB (A)	Cz	L dB (A)	Cz	L dB (A)	Cz	L dB (A)	Cz	L dB (A)	Cz	L dB (A)	Cz
Grinding machines	1.0–1.6	—	—	—	—	—	—	—	—	80	75	83	80
	2.5–4.0	—	—	75	70	78	75	81	75	—	—	—	—
	4.0–6.3	—	—	77	70	80	75	83	80	—	—	—	—
	6.3–10.0	—	—	77	70	80	75	83	80	—	—	—	—
Shaping machines	1.6–2.5	75	70	—	—	—	—	—	—	—	—	—	—
	2.5–4.0	80	75	—	—	—	—	—	—	—	—	—	—
	4.0–6.3	82	80	—	—	—	—	—	—	—	—	—	—
	6.3–10.0	85	80	—	—	—	—	—	—	—	—	—	—
Portal milling machines	10.0–16.0	79	75	82	80	85	80	—	—	—	—	—	—
	16.0–25.0	81	80	84	80	87	80	—	—	—	—	—	—
	25.0–40.0	83	80	86	80	89	85	—	—	—	—	—	—

Reaming and milling machines	6.3–10.0	—	—	79	75	82	80	85	80	—	—	—	—
	10.0–16.0	—	—	82	80	85	80	88	85	—	—	—	—
	16.0–25.0	—	—	84	80	87	80	90	85	—	—	—	—
Vertical and universal milling machines	1.6–2.5	—	—	75	70	78	75	81	80	75	—	—	—
	2.5–4.1	—	—	77	70	80	75	83	80	—	—	—	—
	4.0–6.3	—	—	79	75	82	80	85	80	—	—	—	—
	6.3–10.0	—	—	82	80	85	80	87	80	—	—	—	—
	10.0–16.0	—	—	—	—	87	80	—	—	—	—	—	—
Boring machines	1.0–1.6	—	—	—	—	75	70	78	75	80	75	—	—
	1.6–2.5	—	—	—	—	76	70	79	75	80	80	—	—
	2.5–4.0	—	—	75	70	78	75	81	75	—	—	—	—
	4.0–6.3	—	—	77	70	80	75	83	80	—	—	—	—
Normal and revolver lathes	1.6–2.5	—	—	—	—	77	70	70	75	85	80	—	—
	2.5–4.0	—	—	—	—	79	75	82	80	85	80	—	—
	4.0–6.3	—	—	—	—	81	75	84	80	90	80	—	—
	6.3–10.0	—	—	—	—	83	80	86	80	90	85	—	—
	10.0–16.0	—	—	—	—	85	80	88	85	—	—	—	—

In order to efficiently detect and supervise the spoilage that can appear, the supervising and diagnosis systems must follow a minimum set of requirements:

Adequate match to the supervised machine tool or tool, having the necessary precision and ability to detect the faults.

Fault warning must be made on time, and false alarms must be avoided.

Location of the faults must be determined in order to minimize the intervention time for repairs.

Correlation of many parameters that accompany the machine functioning (vibration, noise, temperature, pressure) must be ensured in order to have as much complete and correct information as possible.

The reliability of the supervising/diagnosis system must be superior to the reliability of the measured system.

The system has to be easy to use and maintain, and be resistant to dust, dump, and industrial liquids, low and high temperatures, and sometimes to radiation.

The system must not be connected to the same energy sources as the supervised system but to special stabilized and protected sources.

The cost of the supervising system, including its installation, should have reduced weight, usually under 10% of the cost of the supervised system.

1.3.3 Stages of Technical Diagnosis Implementation on Machine Tools

It is possible to establish technical diagnostics for complex systems such as machine tools only after knowing their dynamics and kinematics. By comprehending these elements, the parameters that have to be supervised, the types of transducers able to be used, and also the points where they will be installed can be established. When processing the signals, it is necessary to keep in mind the normal and maximum admitted levels of the supervised parameters. Figure 1.6 presents a pyramid of the stages that must be crossed in order to conceive a diagnostic system for a given machine tool or manufacturing process.

The sensible points of the supervised systems are: the *signal processor*, which has to extract from the raw signal the necessary data, and the *diagnosis processor*, which has to use the data in order to identify the

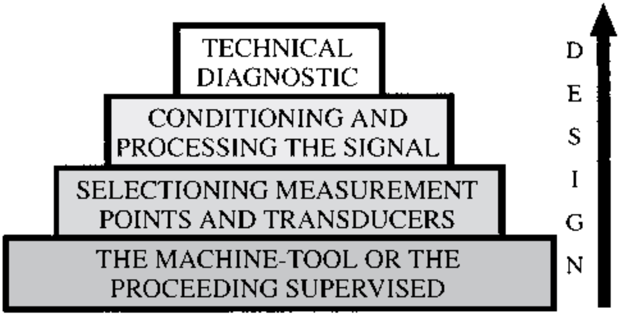


FIGURE 1.6 Pyramid of a proposed diagnostic system.

state of the supervised system and to locate and isolate the fault. This should be done according to the specific algorithms of the diagnostic proceeding used.

1.3.4 Efficiency of the Diagnostic Systems

The term "efficiency" designates the ratio between the ensemble of the effects obtained as the result of an activity and the totality of effort (expenses) that this activity implies. In the case of technical systems, we can speak of the introduction efficiency of technical diagnosis.

Concerning the expenses implied by the introduction of the diagnosis system, the following must be taken into consideration.

The supervising/diagnosing equipment has to be adjusted to the supervised parameters.
The sizes and the complexity of the supervising system.
The cost of the supervising system, installation, and maintenance.
The cost of training personnel.

Concerning the useful effects, these are manifested by the following.

Significant increase of effective production time. It was noticed that for machine tools without monitoring only 10% of the theoretical production time could be reached, and for machine tools having supervising systems and diagnosis, the production time increased up to 60% from the theoretical production time.
Reduction of accidental interruption times, and also decreasing of the time necessary for repairing.

Decrease in the consumption of cutting tools and elimination of waste because of the supervising during the time of the cutting process, including wear and breakage of the tool.

Sustaining the adaptive command for using the intensive cutting regimes in order to increase productivity.

Recent studies have shown the economic efficiency of introducing diagnostic systems, estimated on the basis of the above criteria, increased on average from 2 to 3% of the value of the net production. Of this percentage, 65% is the effect of avoiding production stoppage, and 34% is the effect of reduction of maintenance and repairing costs [54, 108].

1.4 VIRTUAL INSTRUMENTATION FOR ESTABLISHING TECHNICAL DIAGNOSIS

The analysis and measurement branch of industry is undergoing spectacular changes because of rapid developments in hardware and software technology. In research, designing, testing, measuring, and control activities, PC computers are being used more and more, so companies producing instrumentation have reoriented methodologies and measurement equipment in order to better exploit the PC's hardware and software resources. On the other hand, the limits imposed by the rigid architecture of traditional instruments has generated, during this time, nonconcordances between the offer and the functionality request, namely, between what the instrument producers offer and what the user wants.

In the last decade, the idea of combining a new measuring instrument programmable by standard PC computer has led to the creation of a new concept, that of "virtual instrumentation," whose functions are defined by the user and not by the producer. This innovation became possible only after the appearance of digital instruments and the communicating interface type GPIB (general purpose interface bus). Through this interface, these digital instruments can now be controlled by a program. The current generation of technical measurement offers more flexibility and performance since the instrument itself is built as a component of the PC.

In 1986 National Instruments (Texas) Company launched the first release of virtual instrumentation software for engineering purposes, named LabVIEW (Laboratory Virtual Instrument Engineering Workbench) 1.0. This software uses a graphical programming language G in order to create programs shaped as block diagrams, without sacrificing any of the power of a traditional programming language. LabVIEW uses terminology, symbols, and ideas familiar to researchers and engineers, based on graphical symbols rather than on textual language for describing programming activities. LabVIEW combines the most recent operating system technology with specialized programming techniques (OOPT, object-oriented programming techniques) in order to obtain a simple and flexible operating environment.

Under the slogan, "The software is the instrument," the National Instruments Company identifies and structures the steps for use of the virtual instrument (Fig. 1.7):

At the first level, the virtual instrument uses hardware controllers and interface type GPIB for connection with the programable instruments.
At the medium level, the virtual instrument uses standard hardware architectures and corresponding drivers (specific driver packet containing libraries for the functions that operate the hardware).
The superior level is represented by the software applications LabVIEW or LabWINDOWS.

The Danish firm Brüel & Kjær, specializing in measurement equipment for the vibroacoustic domain, in 1992 culminated their efforts of

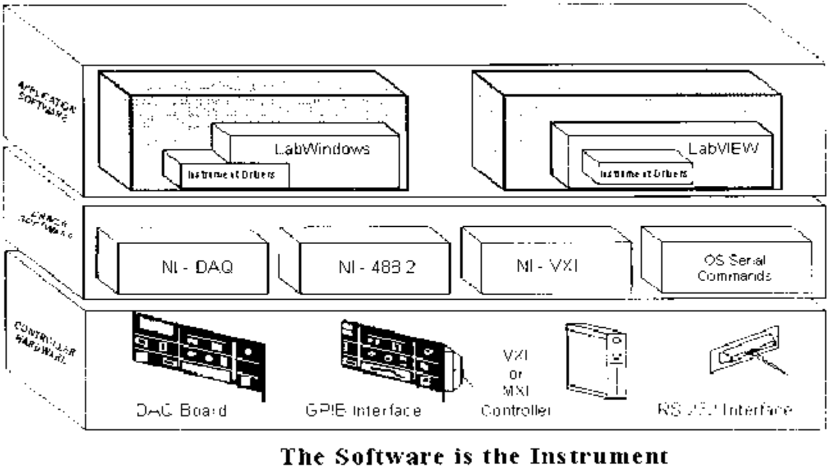
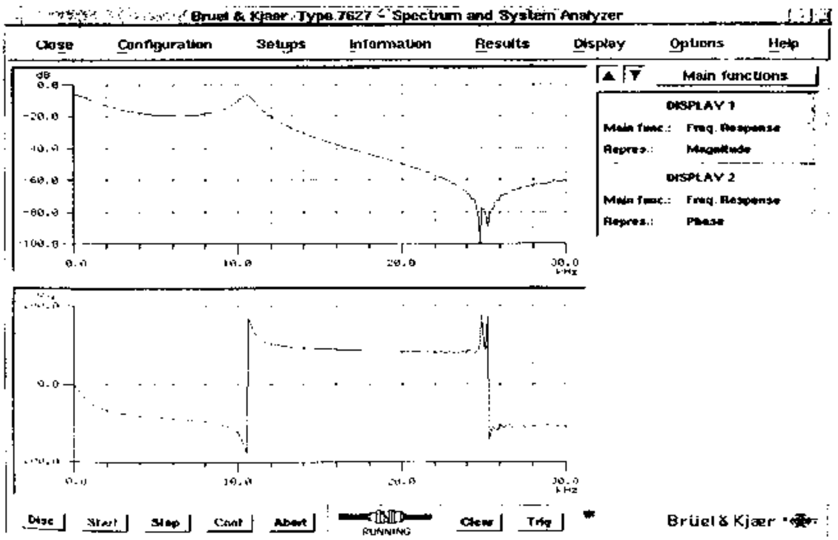


FIGURE 1.7 Virtual instrument usage steps.

integrating the computer in the measuring chains by launching the software *Modular Test System Type 3538*. The company, which has had exceptional experience in the field of signal processing with dedicated traditional equipment, created a virtual instrumentation that couples widely used classic instruments with a powerful software capable of providing the instrumental functions that the user needs. Moreover, using the X-Window System and Motif application, the user can create and use his own instrument, front panels, and graphical interfaces. The performance of the virtual instrumentation launched by B & K is based on two special qualities: the precision of the digital/analogue and analogue/digital conversion and the processing power of the digital signal.

Figure 1.8 presents the front panel of one of the most powerful virtual instruments offered by the B & K company, a double-channel spectral analyzer, Spectrum and System Analyzer Type 7627. It includes not only the measuring instrument but also the signal generator and realizes a large range of procedures such as spectral analysis, measurement of frequency response, measurement of harmonic distortions, simultaneous measurements in time and frequency (wave shape, magnitude spectrum,



DISPLAY 1
Main func.: Freq. Response
Repres.: Magnitude
DISPLAY 2
Main func.: Freq. Response
Repres.: Phase

FIGURE 1.8 Front panel of the double-channel spectral analyzer, the Spectrum and System Analyzer Type 7627.

and the phase, coherence, and correlation functions), and finally, testing and finding the measurement schema faults.

The flow of information in this measurement and analysis system is indicated in Figure 1.9. The physical signals enter the instrument by the hardware module, which is controlled by a dedicated driver. The server for measurements controls this driver, conceiving an interface between the hardware and the virtual instrument. The virtual instrument takes over and processes the data on the basis of its functions, and the results are communicated to the operator by the front panel.

The well-known German firm, Hottinger Baldwin Messtechnik, has merged with the Group Spectris concern, which produces control and measurement equipment and has introduced in its turn virtual instrumentation as a working environment. The new generation of Hottinger equipment is adapted to acquisition, computerized processing, and analysis of signals. Moreover, one of the fields of interest of the company is monitoring industrial processes.

A virtual instrument is defined as being a software/hardware interface that is added to the computer in such a way that the user can interact with it as she interacted with the traditional instrument. This instrument can accomplish a compulsory family of functions.

1. The function of data gathering is executed through a data acquisition board, connected straight to the processor bus; the memory registers from this board are accessible to addresses from the I/O space of the computer memory. The computer controls the data acquisition

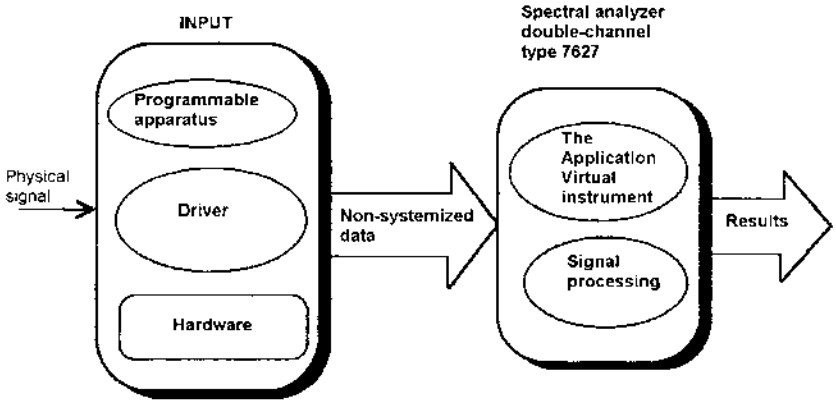


FIGURE 1.9 Flow of information in measurement and analysis system.

board, and the data transfer between the board and processor is made using hardware interruptions on DMA dedicated channels. The problem that arises when performing this function is that of the speed of data acquisition: the computer can not compete with the dedicated processor of traditional instruments, even though the computer is completely occupied with solving the operation executed by the virtual instrument. The computer interruptions have priorities, and they are stored in a waiting file that results in an increase of the working time. Traditional instruments can usually gather data with a speed of 10 GHz, but an acquisition board does not surpass the speed of 1 MHz. The solution for this problem is to endow the acquisition board with counter/timer chips that use internal frequencies up to 10 MHz. In this way, the data acquisition will be made correctly by the virtual instrument, which means to the speed specified by the user. The concurrence of tasks that have to be solved by the computer's processor eventually may delay data storage and/or the presentation of the results.

2. The data analysis and control functions are completely carried out by the hardware already existent in the computer and by the software that, to a large measure, is already familiar to users. The virtual instrument uses, as do traditional ones, software modules from a large package, but the difference is that as traditional instruments close this software on its RAM memory, the virtual instrument holds the functions on the computer's hard drive or on a floppy disk that can be installed on every computer. Moreover, many virtual instruments can coexist on the same computer, using the same display, independently or in direct relation with one another.

3. The function of results display is another compulsory function. The existence of a driver with a graphical interface enormously diminishes the handling and control of the application. The instrument is presented on the virtual panel display on the computer's monitor, and may look like the front panel of traditional instruments. The virtual panel has in its background the software program, which means the instrument commands that are blended into that application, together with the acquisition routines, data analysis, graphical presentation, and finally the capacity to eventually store data/results in files. This construction of the virtual instrument makes possible, for the first time, for its functionality to be defined entirely by the user. The virtual instrument uses standard hardware architectures and corresponding drivers, which is a specific package with libraries that operate the hardware.

In principle two programming methodologies exist for the use of virtual instrumentation:

Graphic programming, such as LabVIEW software
Programming in a traditional language, which is the case of LabWindows/CVI (C for virtual instruments) software [160]

Launched on the market during the second half of the 1990s, virtual instrumentation has seen great development and, nowadays, is a standard factor in testing and control.