8

Final Conclusions and Original Contributions

8.1 GENERAL ASPECTS AND CONCLUSIONS—RECOMMENDATIONS

The performance of modern machine tools and the utilization of electronics in machining processes headed the growth of the field of technical diagnosis, a very important field of research.

Machine tools are complex dynamic structures that contain various sources of noise and vibration. Consequently, it is supposed that the noise and vibration are determined by the characteristics of the component mechanisms and subsystems. Also, both the parameters of the working regime and the characteristics of material workpieces have a great influence on these phenomena.

Research for the evaluation of machine tools is now channeled in some meaningful directions:

Diagnosis of wear and wreckage of cutting tools
Diagnosis of bearings, especially those for main shafts
Diagnosis of adjusting mechanisms such as the gear box or feed box

In order to use vibroacoustic evaluation for machine tools, this book describes the specific sources of noise and vibration for machine tools, the requirements undertaken for the diagnostic systems, and the steps needed to build those systems. The book emphasizes the advantages of diagnostic systems utilization related to the cost of investment for their implementation, and it also draws some conclusions regarding the efficiency of the utilization of diagnostic systems for machine tools that are integrated into manufacturing technological systems.

This research starts with a documented study of the fundamentals of establishing a technical diagnostic for machine tools. It illustrates the diagnostic methods and techniques applied to the elements of the machine tools' kinematics chain: rolling and sliding bearings, gear and belt transmissions, and other rolling parts. The researchers are interested in the identification and interpretation of these vibration sources while, from the acoustic point of view, the modern tendency is towards the supervision of acoustic emission ($f > 100$ kHz), a method which gives information from the microphenomena field of physics. This book presents current results obtained in the field. It has studied the diagnosis of electrical drive engines, the main sources of noise and vibration, from the mechanical, magnetic, and aerodynamic phenomena points of view. The principal aspects for diagnosis of the cutting tools and the machining process are displayed in this research because the machine tool can not be separated from the context in which it does work.

In order to determine the relationship among source–signal–working condition, one should choose adequate parameters, diagnosis criteria, proper algorithms, and admissible levels for the chosen parameters. These principles have been followed during the elaboration of different diagnostic methods. The authors grouped these in two categories: (a) surface diagnosis methods (the peak element method, diagnosis index method, kurtosis method, and the shock impulse method); and (b) profoundness diagnosis methods (the spectral comparison method, evolute method, Cepstrum analysis method, and acoustic emission method). While the first group shows the working condition and/or the existence of a defect, the methods from the second category can be used in order to appreciate the type, the place of the defect, and the time until the working condition reaches the end. The book illustrates the theoretical basis of the above-mentioned methods and refers to their utilization domain and the way they can be used for the diagnosis of machine tools, cutting tools, and the machining process.

The physical model of the feed kinematic chain has been analyzed using the diagnosis method in order to see if it is adequate for studying diagnostic problems of the elements included in its structure. The working process on the machine is stable if the structure of the machine tool has an adequate dampening capacity in order to minimize the forced and self-excitation vibrations; otherwise the working process becomes unstable and the machine chatters. The dynamic stiffness of the machine tool is very important for determining system stability.

The results and small differences between the estimates of proper structure frequencies using the analytical technique (finite element method) and experimental technique (Nyquist diagram) confirm the adequacy of the model. Moreover, analyzing the deformations of the physical model demonstrates that the most important deformation shows up in the area of the mechanisms that are inclined to defective wear: ball screw-nut transformation mechanisms and rolling slides of the longitudinal carriage. These failures can influence the working of the mechanisms, hastening the appearance of the failure processes that can drive the mechanism wreckage. However, if the structure's proper frequencies are known, one can compare these frequencies with those of all the mechanisms from the studied kinematic chain. Based on theoretical and experimental research and studying the literature in the field, it can be shown that these working frequencies are situated in a smaller field compared to the proper frequencies.

For an element that has mechanical defects, significant increases in the power range show up not only for characteristic frequencies but also for their higher values; it is possible for resonance phenomena with proper frequencies to appear. This can lead to the discovery of mechanical defects and to stoppage of the machine tool without any reason.

The development of virtual instrumentation is necessary because of the rapid transformations in the field of measurement devices, and because of the extraordinary performances of computers; this should be taken into consideration when establishing the technical diagnosis. Introducing computerized machining techniques in the field of signal acquisition and evaluation means an important gain regarding the rapidity, reliability, complexity, and flexibility of data measurement and processing.

This book presents original virtual devices that have been developed by the authors for surface and profoundness diagnosis. The devices were built using the structures presented in Chapter 3. The front panel with instructions was shown and the detailed block diagram presented for every built virtual device. The authors have identified the main noise and vibration sources from feed kinematic chains. The theoretical approach allows the calculation of characteristic frequencies of the motion elements from these kinematic chains.

Preliminary experimental research, started in 1992, used traditional acquisition and machining drafts based on the physical model; they operated on a testing stand that was conceived by making small adjustments to an existing machine. Experiments have been done using a multichannel acquisition system (produced by S.C. Emco S.A. with an eight-byte board and software created by the company specialists). These tests have shown the correlation between the appearance of failure factors, then of mechanical defects, and finally the indications of diagnostic methods. The FFT transformation of acquisition signals allowed the comparison of the frequencies induced by defects and characteristic frequencies of the studied mechanisms. It was demonstrated that knowing the characteristic frequencies during the analysis of acquired vibroacoustic signals is very necessary.

The utilization of virtual instrumentation for experimental research using virtual devices has settled a comparison with the same diagnostic methods but accomplished by traditional instruments. The conclusion is that the virtual instrumentation is the best because it can be easily utilized, and it is very precise. Also, the results indicate that virtual instrumentation is satisfactory for use in vibroacoustic diagnosis. The virtual instruments achieved are operational and can be found in S.C. Eurotest S.A. laboratories; this company offered the necessary logistic support throughout the experiments. The methodology and measurements plan indicated that experimental research imposed by the diagnostic techniques should be done in normal conditions and accelerated tests. The utilized diagnostic methods proved that they were efficiently chosen, leading to a correct and precise evaluation of the working conditions of the controlled elements.

During the trials, the unmistakable correlation between the vibrating signal and the working condition for some constitutive mechanisms of feed kinematic chains was emphasized. As to the use of noise as a diagnosis basis, the main disadvantages of signal catching and processing were presented. At the same time, the correlation between noise and the vibratory signal global level was pointed out. The simultaneous utilization of different diagnostic techniques and the accumulated experience led to a firm conclusion: monitoring the working condition of the machine tool or of the constitutive elements should be realized using time domain techniques and establishing the technical diagnosis should be accomplished using frequency domain techniques.

The book utilizes parallel processing theory in order to capitalize the research database. With this type of information processing experiential knowledge can be stored, which is why the neural network was created. Two diagnostic neural networks have been elaborated: one for choosing the good bearings from bad ones, and the other, more advanced, which is capable of classifying the bearings' working condition into four categories, ranging from good to bad. Information processing using neural networks is a viable competitor to classic techniques for monitoring and diagnosis. A comparison between the success ratio of these techniques and those based on neural processing will definitely favor the latter.

8.2 ORIGINAL CONTRIBUTIONS

From the theoretical point of view this book displays the following original aspects:

- The identification of noise and vibration sources from feed kinematic chains
- The elaboration of a reckoning method for characteristic frequencies of the ball screw-nut mechanism
- The method and calculation of characteristic frequencies for ball tankettes
- The introduction of virtual instrumentation for machine tool diagnosis
- The development of three virtual instruments for surface diagnosis, based on verified diagnostic methods, using time signal processing
- The elaboration of two virtual instruments for profoundness diagnosis, based on competitive methods from the signal frequency processing domain
- The introduction of information neural processing for machine tool diagnosis
- The generation of a multicriteria neural network having data from experimental research, which creates a network capable of recognizing perfectly working bearings from deficient bearings

The elaboration of a neuronal network able to perceive the working condition of the bearings
The realization of a diagnostic analysis, using the finite element method, for the physical model of the feed kinematic chain
The systematization of theoretical and experimental diagnostic methods in order to establish the technical diagnosis of machine tools
The elaboration of some conclusions and recommendations regarding the diagnosis of vibroacoustic methods and their application for machine tools

From the point of view of experimental research, the original contributions refer to:

The investigation of the correlation between some statistical parameters of the vibration signal and the working condition of some ball bearings and needle bearings
The experimental identification of characteristic frequencies of some elements from feed kinematic chain structures and their comparison with the theoretic frequencies
Research aspects of determining the technical diagnosis using frequency analysis of the vibration signal
Diagnostic analysis of the physical model stability using a Nyquist diagram and the identification of the weak points in the system
The testing and utilization of original diagnostic virtual devices, both for surface diagnosis and profoundness diagnosis
The testing of the neural networks with experimental unsystematized data and the checking of their estimation capacity from the point of view of the working condition

8.2.1 Perspectives for Continuing Research

Based on the virtual instrumentation obtained, the concept of vibroacoustic diagnostic equipment may begin. The virtual instruments can be transformed into implemented programs that, together with an adequate hardware interface, can be easily used by everyone.

The theoretical and experimental research on working frequencies for the mechanisms of machine tool kinematic chains should continue based on the research methodology illustrated in the book. Research for correlating many different parameters in order to establish the technical diagnosis in machine tools and the machining domain should also be continued, as should the development of a database regarding vibroacoustic diagnosis and its use in processing information through neural network techniques for learning by practice.

Conceiving and developing diagnostic expert systems specialized for machine tools, including the diagnosis of cutting tools and the machining process is another area for future work.