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# DYNAMIC BEHAVIOR STUDY USED IN RETROFITTING OF A LATHE FOR RE- PROFILING RAILWAY WHEELSET

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***Abstract:*** *The article is presenting some aspects regarding the research stages achieved for the general purpose of retrofitting a machine tool of lathe type used for profiling/re-profiling of railway wheelset. The process of machine tool modernization is basically one of changing the conventional feed drives with drives corresponding to CNC equipment, reusing the machine tool structure. Therefore, for this purpose the machine tool dynamic characterization was necessary to be done especially on Y and Z axes in order to assess the machine rigidity, high and low frequency domains and amplitude vibrations in idle operation and also during cutting. A specific testing set up was used for the measurements, the results showing good behaviour of the conventional machine which was later subject of feed drive replacement.*

***Key words:*** *retrofitting, railway wheelset, machining, dynamic behaviour, vibrations.*

## 1. INTRODUCTION

For acquiring the technical characteristics of productivity and quality in terms of cost saving, a solution concerning the modernization of the machine-tool feed drives was required of a lathe used for profiling/re-profiling railway wheelsets. The movements supplied by classical drives were subject of change in numerically controlled ones.

Retrofitting is the process of replacing conventional drives of a machine tool by CNC servo and spindle systems to extend its useful life, precision, flexibility and reliability. Remanufacturing typically include a CNC retrofit with the new control elements for each axis [1]. Assuming the machine tool is generally in good mechanical condition, for retrofitting the assessment of main dynamic characteristics is necessary.

Machine tools manufacturers must design machines robust enough to withstand the high mechanical and thermal stresses, while consuming the smallest amount of material and energy [2]. Conventionally, the heavy machines have been oversized to the detriment of energy and material consumption, with the aim of achieving as much stiffness as possible [2].

With the retrofitting solution concerning the numerical control chain integration on longitudinal and transversal axis the dynamic parameters of the machine is necessary to study. The main goal is to obtain the similar stiffness after the retrofitting operation.

In order to implement this solution, a study of dynamic behavior has been achieved so that it can directly assess the machine tool dynamic performances. The experimental procedure was designed to highlight both the static status by measuring geometric elements of the machine and the dynamic one during the rotational movement and cutting process.

Measurable behavior of a machine tool is a combination of the geometric, thermal, static and dynamic behaviors. The dynamic behavior influences directly the machined part quality being observable through a lot of effects, such as the tracking error, outrunning, self excited vibrations, cross-talk, etc. In general, there are some week pints (bottlenecks) belonging to machine tool structure that influences the dynamic errors in a machine tool. Their identification becomes an essential condition for the desired improvement.

A comprehensive study of the dynamic behavior should be achieved by different methods:

- Determination o the frequency answer (natural vibration mode respectively) of the machine tool structure, determined by the mass distribution, stiffness and damping properties in guides and bearings, and also by the degree of structural elasticity (for large frequency ranges).
  - Experimental modal analysis regarding a set of principal forces, and the acceleration signal distributed on the entire structure.
  - Simulation models based on rigid bodies and model with finite elements.
- Structure testing, including the control loop (control coefficients, acceleration and jerk settings), feed-forward, filters, dead time, measuring system, etc.
  - Simulation of the actuating systems, including also the structural machine tool components.
  - Experiments: evaluation o the input signals, cross-talk measurements, subsequent FFT (Fast Fourier Transform) and cross-talk interpretation.

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- Stability measurements (process parameters):
  - on-line measurements on a running machine tool;
  - process model integration in a virtual structure.

## 2. RESEARCH DESCRIPRION

By the literature study the most limiting modes for vibration can be obtained studying the machine structural components [3, 4] presented in low frequency domain, from the spindle-tool holder [5, 6] in high frequencies domain, or from the workpiece, usually higher than 500 Hz [2].

For highlighting the frequency ranges and also for reducing the errors, the direct measurement with transducers or sensors is necessary in order to reduce the transformations and mathematical calculations that result in reduced frequency range. Therefore, for high frequencies, the acceleration is directly measured, and the low frequency range is obtained either by direct measurement of displacement synchronized with rotational speed.

Dynamic stability of the machine is given by the high structural rigidity of the frame and also of the movement transmission elements.

The importance of research is that of highlight the parameters before and after retrofitting.

## 3. Experimental setup

The dynamic characterization of the machine tools IS a prerequisite in choosing and substantiation of technical solution which involves replacing existing parts on the machine with those components that lead to increased productivity and quality of the machined parts. Analysis of dynamic characteristics of machine tools enables the stiffness evaluation and determination the new design solutions of the drives and control systems to be integrated in the machine-tool.

To analyze the dynamic behavior of the lathe for reprofiling railway wheelset, an experimental protocol was designed in order to characterize the machine tool both in idle operation and during the cutting process (Fig. 1).

Experimental tests were made using some equipment for measuring and processing signals in real time: multichannel system CRIO9076 National Instruments with 24 bite resolution, sampling rate 100 kS/s/ch; acquisition module National Instruments USB 4431, resolution of 24 bits sampling rate of 102 kS/s/ch; accelerometers Bently Nevada with sensitivity of 4mV/mm/s; uniaxial accelerometers Monitran with sensitivity of 500 mV/g; contactless displacement sensor of thr type Sensonics with sensitivity of 4 mV/µm; laser speed sensor; analysis software Fastview; recording and processing of signals in real time; continuous synchronization of vibrations.

Measuring system has the advantage of monitoring and diagnosis in real time so that during the cutting process we can properly assess the quality of the dynamics of the machine. Thus, the transducers and sensors are fixed for three-dimensional measuring of the processing system (Fig. 2). They were positioned in the three-dimesional configuration in XYZ axis on the radial slide. The measurement on the radial slide has the major importance because the machine rettrofiting requires the integration of a profile metrological system. For the metrological system of measurement and control it has been chosen as a fixing solution the tool holder slide by achieving a pocket in which it can be mounted.

The conventional structure of the longitudinal feed drive contains more than one axis and few gearings transmitting the motion between an electric motor and a lead screw-nut mechanism (Tr 60 × 8). Figure 3 shows an image of the lead screw and nut mounted in a support on the longitudinal slide. The final three axes and two gearings are shown in Fig. 4.

## 4. RESULTS AND DISCUSIONS

The importance of dynamic analysis of machine operation is essential for evaluating vibration behavior of the machine during the cutting process.

The emergence of dynamic vibratory phenomena during cutting is caused by excitation of the elastic system: machine tool–fixtures–cutting tool–workpiece. These phenomena are inevitable. When the vibration amplitudes exceed certain limits, they are responsible for the part quality, premature wear of the cutting tool or elements of the machine tool.

Considering that the speeds are low (10–18 rev/min), the frequency range is also a reduced one having low frequencies requiring the use of relative displacement sensors of proximitor type with the sensitivity of 4 mV/mm, and measurement range of ± 2 mm. Synchronization of the vibration parameters is done using a speed signal provided by a laser speed-sensing type.

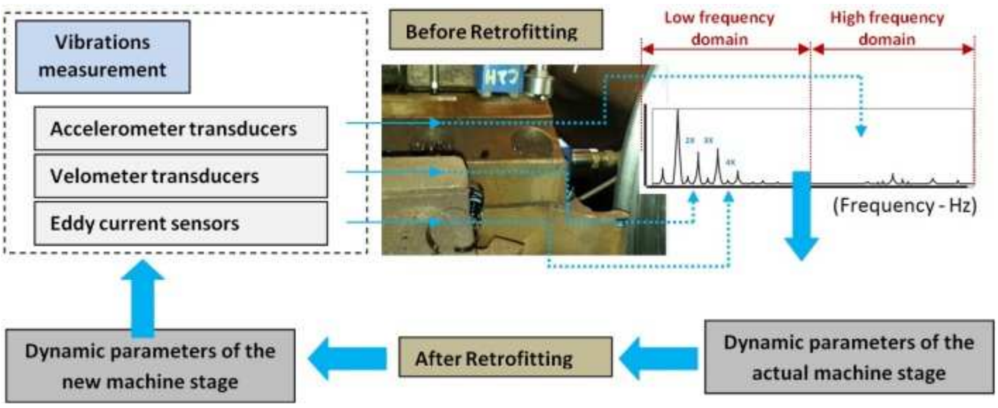



**Fig. 1.** Research synopsis.


**Fig. 2.** Experimental set up.

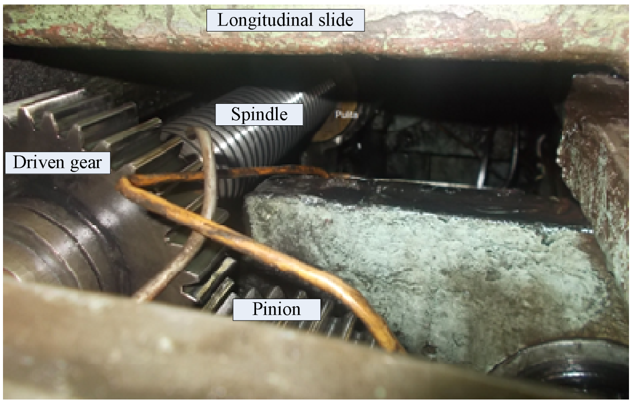



**Fig. 3.** Detail of the conventional lead screw used for moving the longitudinal slide.

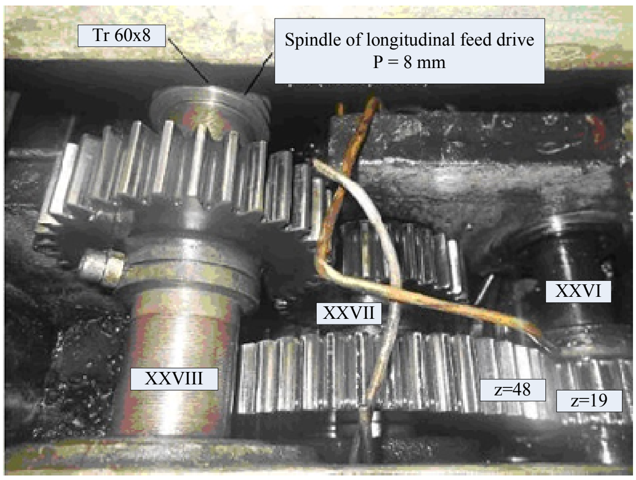
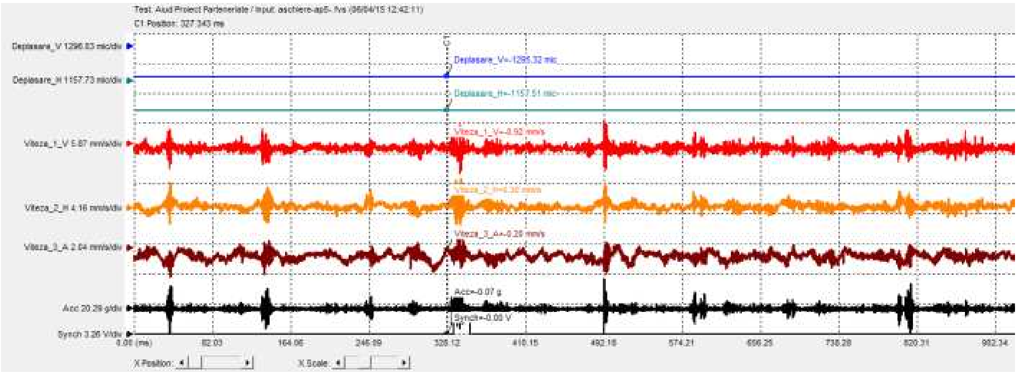



**Fig. 4.** Detail of the gears used in motion transmission in longitudinal feed drive.

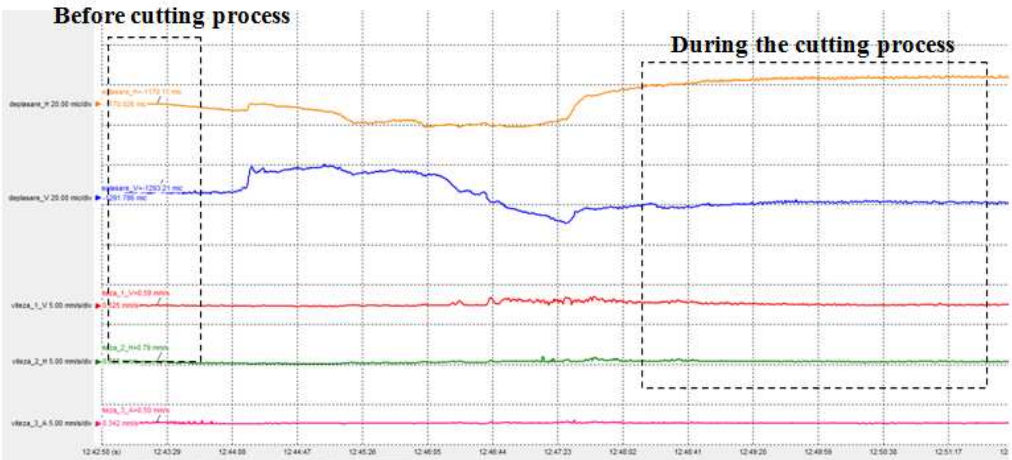
Dynamic assesing fo the machine tool is one of the prerequisites for the subsequeant mechanical interventions to modernize for increasing the productivity and quality of processing. In Fig. 5 it is presented the trend diagram and evolution of the measured parameters in idele operation and during cutting.

It can be noticed the reduced variation of the amplitude between the two situations, highlighting the stable behavior of the machine tool in machining at a dept of cut $a_p = 7$ mm.

The stability is confirmed both by the relative displacement in the cutting process with a maximum of 15 μm and the speed of vibration reaching a maximum of 0.13 mm/s rms. On the evolution chart of the measured parameters one can notice the existence of some amplitude variations in travel that reach up to 25 μm being generated by the degree of error of the mechanical driving system and also of the electrical and hydraulic ones. Also, these variations can be observed on the waveform of the measured signals where the impacts of the gears in the gearbox are present.



a




b

c

**Fig. 5.** Experimental results: *a* – waveform signal-time domain; *b* – parameters trend; *c* – frequency domain.

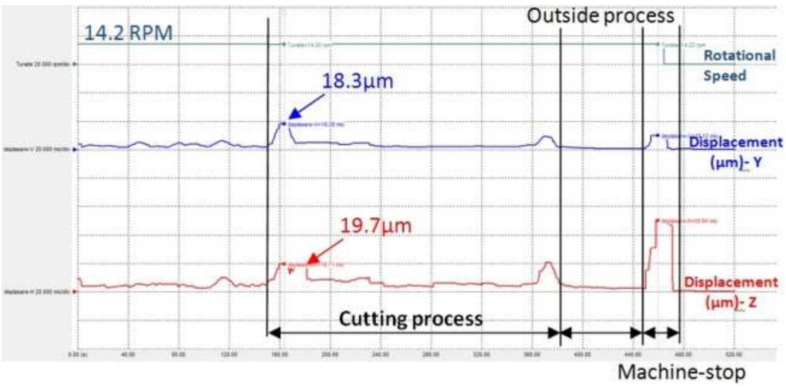



**Fig. 6.** Vibration displacement on *Z* and *Y* axis during the cutting process.

The spectral components of vibration speed highlight this behavior. The required mechanical interventions with planned actions for the machine modernization imply: assessing the gear state, existing backlash, change of bearings and lubrication system verification.

After analyzing the dynamics of the measured parameters one can conclude that the machine has good dynamic stability with high rigidity given by the overall machine construction. The amplitudes measured have the following quantities (Fig. 6):

- in idle operation the displacements on *Z* and *Y* are in the range 3–7 µm;
- during the cutting process with constant radial depth of cut the amplitudes are situated in the range 5–20 µm.

The absolute vibration parameter measured through speed vibration and acceleration transducers were around values 0.3–0.8 mm/s for a stable cutting regime. Both movements and speed vibration show that the amplitude is heavily influenced by the variation in depth of cut. Machining on the machine tool in regime of dynamic instability leads to a high increase of the amplitudes reaching up to 55 µm.

Considering the remanufacturing stage by replacing conventional components and assemblies of the feed drives with some appropriate to CNC solutions, one must take into account of the machine stiffness. The machine shows good dynamic stability given by the bed rigidity and existing kinematic couplings. After evaluating their dynamic behavior it was concluded that the new elements will be implemented to ensure the same dynamic condition of rigidity and precision. This means using coupling and power transmission elements with high precision and having the possibility of adjusting and compensating for the axial and radial plays that could arise during machine operation. Therefore, some of the redesign tasks were the followings (Fig. 7):

- Change of electric motor with an synchronmotor electric motor with speed *n* adjustable in the range 0 – 3000 rpm, *P* = 3.3 kW, *M* = 16 Nm, with incorporated gear 1:7.
- The arrangement motor-support-plate is mounted on the front wall of the longitudinal slide.
- Short feed drive with mechanisms placed on the same axis, with elimination of gears.
- Insertion of a coupling between motor and spindle.
- Use of a mechanism ball screw-nut 50x10 mm with double nut for eliminating the backlash.
- Front bearing arrangement with a pair of angular ball bearings working in "O" with possibility of preloading for ensuring a better rigidity.
- Smulation and optimisation of the feed drive [7].
- Adapting a CNC equipment for controling the axes in the profiling process [8].

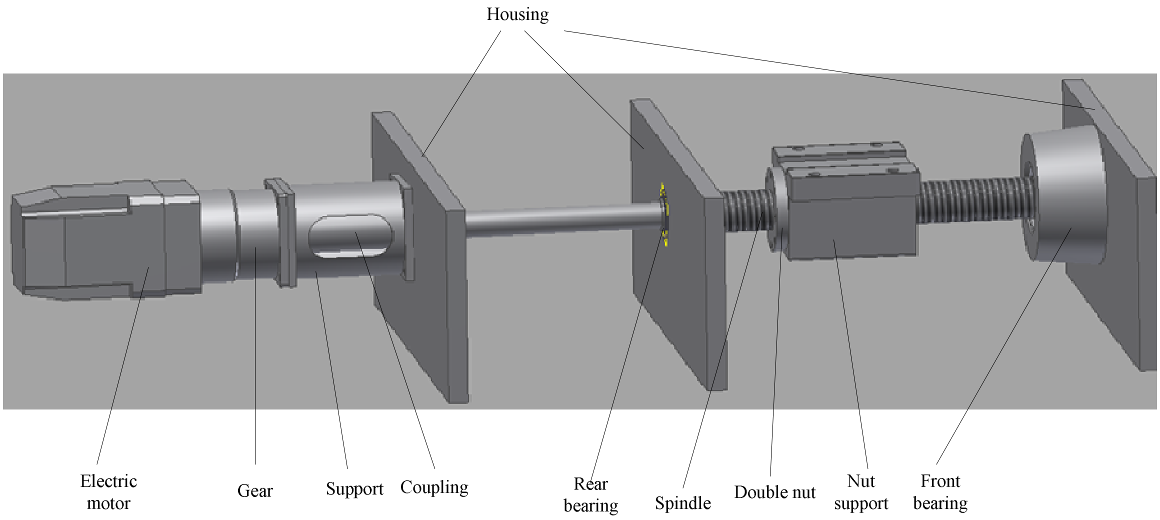



**Fig. 7.** 3D model of the assembly of feed drive in the longitudinal direction.

## 4. CONCLUSIONS

The analysis of dynamic parameters in a machine tool is a basic element in knowing the stiffness characteristics of machines and in determining the limits of stability in the cutting process. A machine tool which is undergoing a process of modernization needs the confirmation of keeping the stiffness levels after the improvement done.

Thus, an experimental protocol was designed to highlight two main frequency ranges: high frequencies and low frequencies.

The high frequencies domain is used for bearing and gear analysis. The gear mesh show a health state without the presence of any defect. Regarding the bearings, they will be changed along with new ball screws.

The vibration amplitude in the two ranges is 20 µm and 0.8 mm/s rms. The vibration value measured is according with ISO standard: ISO10816. The tool holder slide of the *X* axis presents a higher stiffness and provides good stability for control measuring process.

Given the retrofitting stage of components by replacing conventional solutions based on advance CNC it must be taken in account the stiffness of the lathe. The machine frame shows good stability on dynamic and kinematic couplings. After evaluating their dynamic behavior, it was concluded that the new elements will be implemented to ensure the same machine condition. This calls using couplers and power transmission with high precision and with the possibility of axial and radial compensation of the displacement errors that may arise during operation.

The final general conclusion is that the machine tool can meet the stiffness conditions for a machine tool with operation specific to a CNC machine tool.

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