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DYNAMIC ASSESSMENT OF RETROFITTED NC LATHE USED FOR RESHAPING WHEELSETS

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Abstract: *The paper presents the requirements and achievements in a frame of a research project for the retrofitting of a lathe in order to optimize the reshaping on CNC machine tools and increase the traffic safety. It presents the main objectives that have been achieved, with the evaluation of the existing machine in the conventional form, the technical aspects regarding the wear of the used rolling surfaces, the analysis of the new solutions of the radial and longitudinal feed drives, design calculations, choice of the drive motors, CAD modeling and multibody and FEA simulation. The feed drives were designed and assembled on the machine structure along with some components removing. The machine was equipped with numerical control equipment and with surface measuring device before and after processing. Geometric precision measurements have been performed and also the assessment of the idle and cutting operation both on the old machine and on the modernized one. Analyzes of the results and comparisons of the behavior of the refabricated machine tool have been achieved.*

Key words: *lathe, railway wheelset, machining, feed drive, design, retrofitting, dynamic behaviour.*

1. INTRODUCTION

In Fig. 1 the main assemblies of the machine structure are shown: the bed (1), two main spindle housing (2), two longitudinal slides (3), two groups of two radial slides (4) on which the cutting tools are mounted, operator platform (5). The longitudinal and transversal slides constitute a left and right work unit, powered by electric motors for feed and positioning movements. The slides have rectilinear movements in a horizontal plane, in perpendicular directions, for simultaneous machining of both wheels (Fig. 2) of the wheelset [1].

The wheel diameters mounted on the axles are grouped in nine steps, each step being defined between a nominal diameter and the minimum diameter. The first dimensional scale is defined by the diameters D_{nom} = 1000 mm and D_{min} = 920 mm, and the ninth step through the diameters D_{nom} = 390 mm, respectively D_{min} = 330 mm. The roughness of the profiled surface is R_a = 12.5 µm, according to [2, 3].

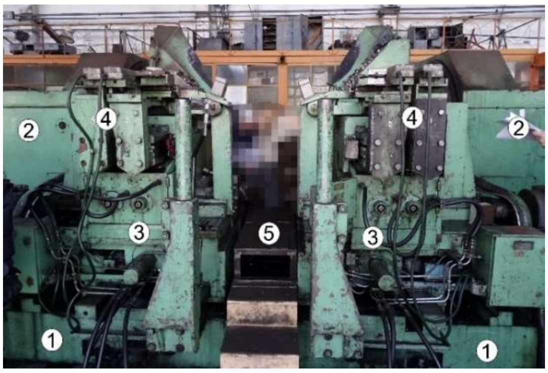

Fig. 1. Basic assemblies of the lathe.

Figure 3 shows an example of a worn rolling surface on all the areas defined in [4, 5]. The weel set having surfaces with such forms of wear require reprofiling machining. The machining is done for both wheels, after gripping at both ends in the main shafts having the the main movement.

2. PROCESS OF MODERNIZING THE LATHE

The process of modernizing the lathe consisted of modifications and adaptations regarding: the kinematic structure, the action, some constructive modifications of

Fig. 2. Worn wheel sets.

Fig. 3. Example of worn wheel running surface.

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elements and subassemblies, the realization and the integration of some systems for measuring the advance and positioning movements, the measurement of the rolling surfaces before and after processing [1]. Previously, in order to evaluate the precision and rigidity of the feed drives of the lathe structure, the behavior in operation and the technical solutions to be applied in the modernization works were analyzed. Some result [7, 8] regarding the geometric precision of the lathe before the refabrication were also analyzed. An important stage of the study consisted in developing and applying specific methodologies and techniques for evaluating static and dynamic behavior [9]. Thus, for the respective machine tool there was an increase in the degree of use in the small / medium series production, an important improvement in the precision of the machining and the productivity of the machining.

Functional, cinematic, constructive, command and measurement improvements were determined by meeting the main requirements for machining the rolling surfaces of the wheel sets, namely: the difference in diameters on the reference circle of each wheel ($\Delta = 0.15$ mm), profile generation accuracy 0.15 mm, fit the roughness to Rz = 10 ... 20 μm. The choice of cutting parameters at optimal values ensures an increase in the quality and productivity of the machining. These processing conditions and results are indicated in the stage reports of the contract and some published papers [10].

The upgraded technological system has resulted in improved technical features, this becoming of average performance.

At the same time, the relations of calculation of the main parameters that define the size of the forces and moments of cutting at the exterior for rough machining have been established and (rectangular, triangular, rhombic, and round) and applied. The analysis was performed for various types of inserts recommended materials. The range of main spindle speed variations D_{nc} = 9 ... 35.5 rpm (step adjustment) and feed speeds D_{vf} = 11 … 22 mm/min (continuous adjustment) were set [11].

The methodology for choosing and using cutting tools with replaceable supports for different plate shapes has been improved to withstand variable loads, corresponding to the v_c and v_f parameters, size of the machining feed and temperatures occurring in the chipping process.

For the modernization of the lathe, calculation and design data were determined for the constructive solutions for the numerically controlled feed/positioning drives (longitudinal and radial), adapting a CNC equipment for controlling drive and measurement systems in simultaneous machining of wheel sets, implementing on each radial slide a wheel profile measurement system before and after machining [12].

Modern methodologies 3D modelling, multibody simulation and FEM analysis were used for sizing of the components, checking, load determination and assessing static and dynamic behavior in operation [10, 13].

3. STAGES OF RETROFITTING

The purpose of the modernization is to transform the feed drives in numerically controlled axes that have specific structures to CNC machine tools. Therefore, the drive will be driven by AC motors with continuous speed control which can drive the movable element directly through a ball screw-nut mechanism. The solution adopted is the direct transmission of motion from the motor to the driving screw (Fig. 4).

The choice of the electric drive motor was made considering the calculated maximum cutting and friction forces and the estimated kinematic chain structure obtained for the synchronous servo motor 1FK7083-2AF71-1CG1-Z, P = 3.3 kW, M = 16 Nm from Siemens, with a 1:7 ratio of the gear. The optimization calculations of the longitudinal feed kinematic chain structure have been performed [14].

The 3D CAD model of the kinematic chain (Fig. 5) was designed.

The drive solution is identical for both work units – left and right. The asynchronous electric motor of the machine tool is dismantled, its driving function for the rapid travel of the longitudinal slide (conventional version) is taken over by the drive motor with adjustable speed (upgraded version) to be mounted and operated on the axis shown in Fig. 6.

The longitudinal feed drive is given as example of machine transformation. Detail of the lead screw for longitudinal slide movement of the initial form of the machine tool is shown in Fig. 7. The gear mechanism

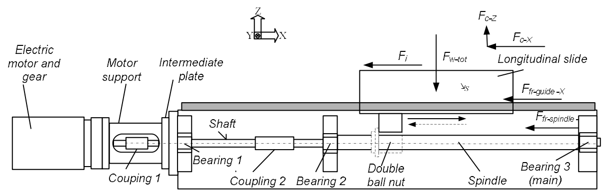

Fig. 4. The kinematic structure of the longitudinal feed drive.

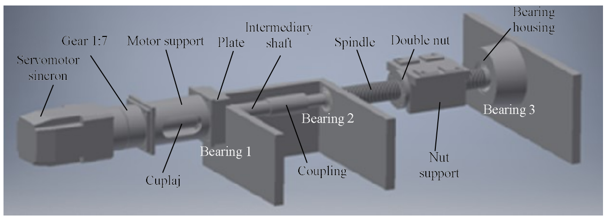

Fig. 5. The 3D model of the longitudinal feed drive.

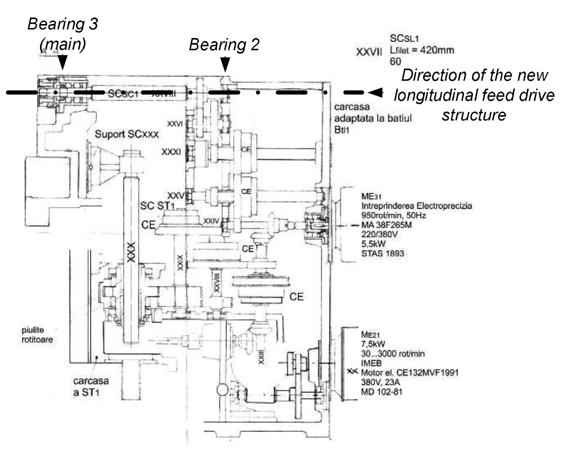

Fig. 6. Conventional structure and new feed drive axis.

and lead screw with trapezoidal thread profile can be observed.

Detail of the longitudinal lead screw including the radial bearing on the intermediate wall of the casing (Fig. 8).

In Fig. 9, a view of the end of the longitudinal feed lead screw from operator side. One observes the screw end of square cross-section of 27 mm dimension used for manual adjustment.

On observes the axial fixed drive bearing body made up of two axial bearings and two radial ones. After studying the drawing of the original bearing support casing, it is possible to draw conclusions about the dimensions of the bearing body and the walls (Fig. 9).

In Fig. 10, there is a lateral view of the LS1 longitudinal slide of the unit WU1 (right), with the indication that the central engine is kept for the positioning of the transverse slide and the left engine is removed.

Fig.7. Longitudinal lead screw – gears and thread.

Fig. 8. Longitudinal lead screw – gears and rea radial bearing.

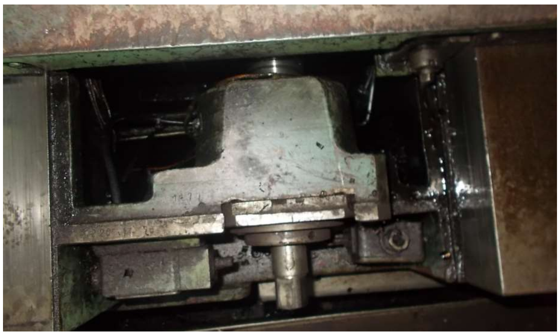

Fig. 9. Front bearing (main) casing.

In Fig. 11, there are components of the old structure of the feed-positioning gearbox for the Z-axis removed and which are no longer functional in the new refabricated structure.

The solution adopted is the one with direct transmission of motion from the motor to the ball screw nut. Driving screw and double ball nut form, longitudinal Z-axis supported by bearings are shown in Fig. 12. The longitudinal cast iron guides were finished.

Figure 13 presents details of double ball nut KSK 16040449-6. Note the rectified external cylindrical surfaces that come into contact with the nut holder bore with a diameter ϕ 90 mm.

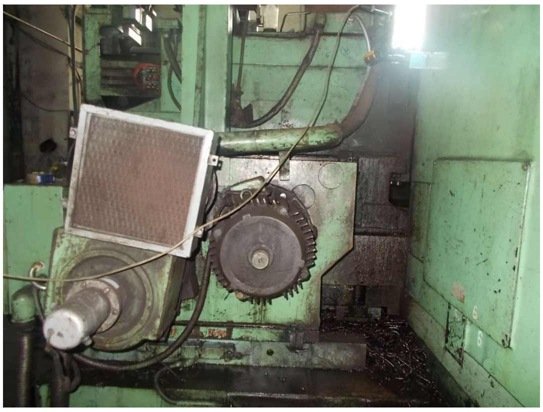

Fig. 10. Lateral view of unit U1.

Fig. 11. Old components removed.

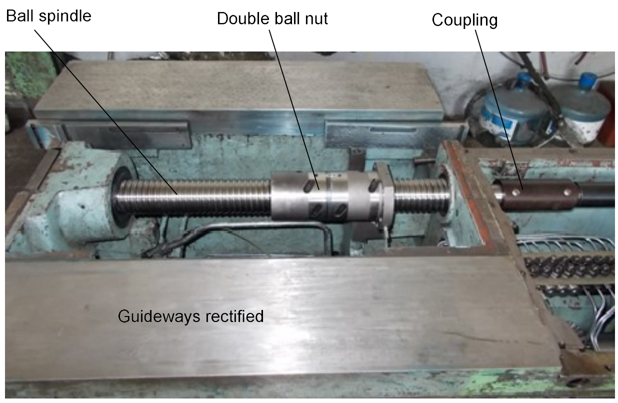

Fig. 12. New longitudinal feed drive – ball screw and nut mounted.

Fig. 13. Ball screw and nut detail.

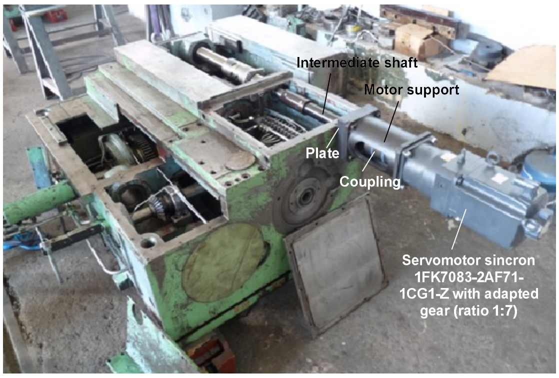

Fig. 14. View of the refabricated longitudinal axis.

Fig. 15. Rear view of the refabricated unit WU1.

On the side wall of the longitudinal slide, the engine is mounted on a support assembled on a plate (Fig. 14). The motor drives the kinematic feed / position chain in the longitudinal direction.

The radial and longitudinal slide assemblies were mounted as general assemblies – the left work unit WU1(Fig. 15) and right work unit (WU2).

4. DYNAMIC ASSESSMENT OF THE MACHINE TOOL

4.1. Experimental setup

To validate the upgrade solution, a dynamic behavioural study was designed to directly assess the dynamic performance of the machine tool. The experimental procedure was designed to highlight the dynamic behaviour of the machine after modernization [15]. The experimental measurements are made both in the idle operation and during the machining.

The analysis of the dynamic features of the machine tool allows evaluating of the stiffness and the validation of the new modernized solutions integrated on the machine tool.

The experimental tests were performed using a National Instrument Board Aquidition equipment, type NI USB 9162 and NI 9233, with 24 bits resolution. The vibration signal was measured with Monitran accelerometers. The recorded signals were processed by the Fastviwe Software.

The measurement system (Figs. 16 and 17) has the advantage of monitoring and diagnosing in real time so that during the cutting process one can properly assess the dynamic quality of the machine [16]. Thus, transducers and sensors are fixed for the three-dimensional measurement of the processing system, three transducers are fixed on each processing direction respectively.

4.2. Results and discussions

The dynamic characterization of the machine tool is an essential condition for the evaluation of the machine after the modernization process [17] and allows for an objective conclusion on the state of the machine's operation.

Fig. 16. Experimental device.

The occurrence of dynamic vibrational phenomena during cutting is caused by elastic system excitation: machine tool / clamping devices / tool / piece and are inevitable [18, 19]. When the amplitudes of these vibrational phenomena exceed certain limits, they are responsible for the quality of the workpieces, for the premature wear of the tool or elements within the machine tool.

Static geometric measurements allowed the geometric errors found on the radial tool / slide assembly to be determined (Fig. 17).

If before the retrofitting the transversal slide deflection was 0.06 mm for the slide 1 and 0.07 mm for the slide 2, after modifications it is 0.013 mm and 0.012 mm respectively. This is due to the reduction of clearance in cinematic couples.

The vibration parameter on *X*, *Y* and *Z* during the 18 workpiece speed is presented in Figs. 18–23.

Fig. 17. Geometrical measurement.

Test: Vibration Analysis
Input: test 1 s1 directie X in gol.fvs (09/14/18 09:20:55)

No.	Parameter	Value	Unit
01	T1	0.19	mm/s
02	T2	0.11	mm/s
03	T3	0.09	mm/s

Fig. 18. Carriage slide no. 1 – vibration on *X* direction.

Test: Vibration Analysis
Input: test 1 s1 directie Y in gol.fvs (09/14/18 10:01:32)

No.	Parameter	Value	Unit
01	T1	0.13	mm/s
02	T2	0.17	mm/s
03	T3	0.14	mm/s

Fig. 19. Carriage slide no. 1 –- vibration on *Y* direction.

Test: Vibration Analysis
Input: test 1 s1 directie z in gol.fvs (09/14/18 09:33:39)

No.	Parameter	Value	Unit
01	T1	0.10	mm/s
02	T2	0.14	mm/s
03	T3	0.29	mm/s

Fig. 20. Carriage slide no. 1 – vibration on *Z* direction.

Parameters Values and Status
Test: Vibration Analysis
Input: test 1 s2 directie x in gol.fvs (09/14/18 09:58:52)

No.	Parameter	Value	Unit
01	T1	0.09	mm/s
02	T2	0.13	mm/s
03	T3	0.21	mm/s

Fig. 21. Carriage slide no. 2 – vibration on X direction.

Parameters Values and Status
Test: Vibration Analysis
Input: test 1 s2 directie y in gol.fvs (09/14/18 09:56:21)

No.	Parameter	Value	Unit
01	T1	0.17	mm/s
02	T2	0.29	mm/s
03	T3	0.50	mm/s

Fig. 22. Carriage slide no. 2 – vibration on *Y* direction.

Parameters Values and Status
Test: Vibration Analysis
Input: test 1 s2 directie z in gol.fvs (09/14/18 09:53:00)

No.	Parameter	Value	Unit
01	T1	0.10	mm/s
02	T2	0.08	mm/s
03	T3	0.18	mm/s

Fig. 23. Carriage slide no. 2 – vibration on *Z* direction.

The dynamic evaluation of the machine is one of the mandatory conditions for subsequent mechanical interventions for the purpose of modernization for increasing productivity and quality of machining.

The vibration parameters measured during the cutting operation is presented in Figs. 24 and 25. The vibration level for idle operation and during the cutting process is according with ISO 10816 for absolute vibration limits.

In Figs. 26 and 27 the spectrum frequency diagram obtained during the cutting operation for both carriage slide no. 1 and no. 2. is presented.

The dynamic behavior for both carriage slides is equivalent, without significant variation. The frequency spectrum (Figs. 26 and 27) presents the same frequency components as before the upgrade without showing any defect.

The dynamic analysis performed both during idle operation and during operation in the cutting process results in a high stability of the tool machine, the rigidity not being influenced by the modernization actions.

Amplitudes are reduced with a slight decrease from the pre-modernization status.

Movement dynamics are manifested by reduced amplitudes at startup with much less impact on shocks than before upgrading (Figs. 28 and 29). The analyzed

Test: Vibration Analysis
Input: test 2 in aschiere sanie s1 h (2).fvs (09/14/18 10:15:51)

No.	Parameter	Value	Unit
01	T1	0.65	mm/s
02	T2	0.45	mm/s
03	T3	0.03	mm/s

Fig. 24. Carriage slide no.1 – vibration on *Z* direction, during the cutting operation.

Parameters Values and Status
Test: Vibration Analysis
Input: test 2 in aschiere sanie s2 h.fvs (09/14/18 10:28:48)

No.	Parameter	Value	Unit
01	T1	0.85	mm/s
02	T2	0.29	mm/s
03	T3	0.12	mm/s

Fig. 25. Carriage slide no.2 – vibration on *Z* direction, during the cutting operation.

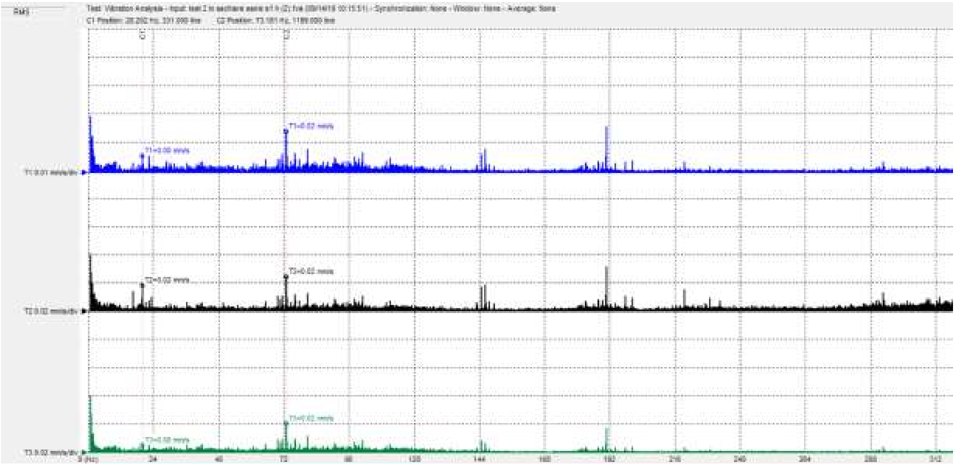

Fig. 26. Frequency spectrum on *Z* direction – carriage no. 1 during the cutting process.

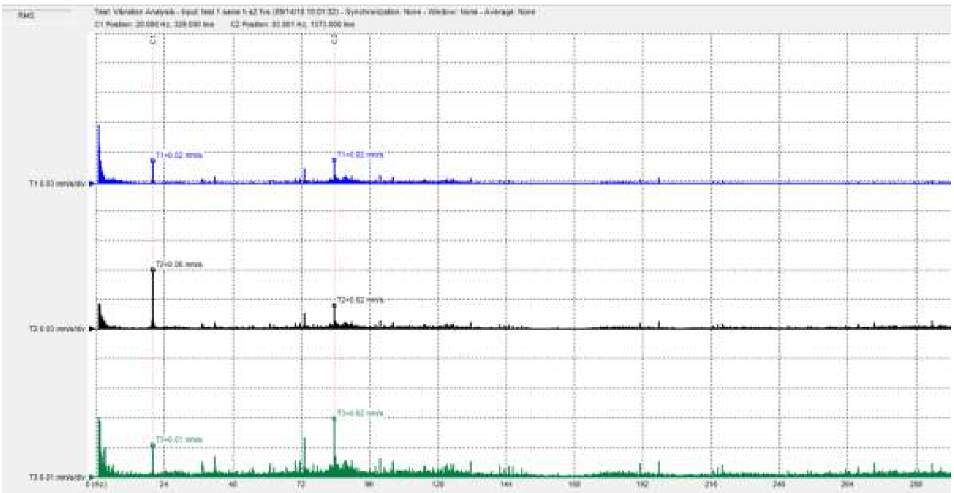

Fig. 27. Frequency spectrum on *Z* direction – carriage no. 2 during the cutting process.

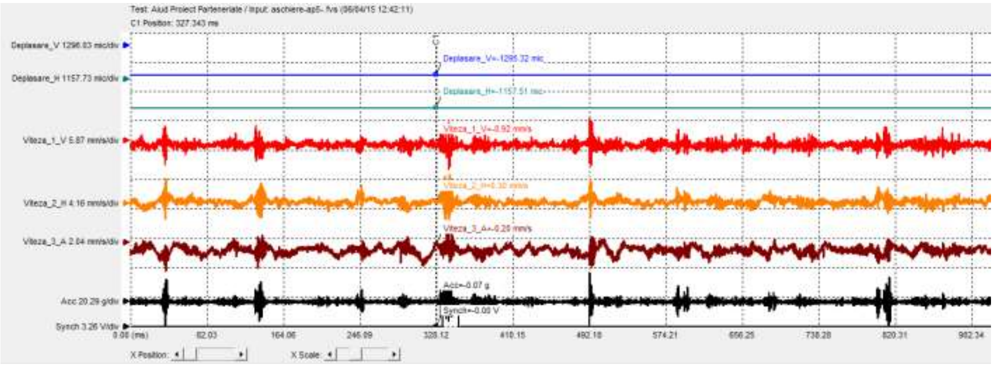

Fig. 28. The vibration waveform during the cutting process before modernization.

Fig. 29. The vibration waveform during the cutting process after modernization.

signals highlight a net global machine tool performance that was dynamically improved with regard to the conventional form of the machine. Dynamic stability is demonstrated by the similarity of dynamic parameters between the idle phase and the processing phase. Modernization of the machine has led to the elimination of some mechanisms as well as transfer ratios that have led to the dynamic improvement of the machine and increased dynamic precision.

5. CONCLUSIONS

The dynamic assessment of machine tool is an important condition to validate the machine's upgrade solution, based on the replacement of the current equipment with those components that will increase the productivity and the quality of the machine parts. This study is designed to assess the dynamic condition of the machine-tool after the modernization process.

The vibration value measured is according with ISO standard: ISO10816.

The machine-tool presents the same level of stiffness as before the modernization. The shocks during the movements were removed and the amplitude variations reduced. The dynamic behavior is similar for each carriage slides, without highlighting amplitude difference between the two.

Global conclusion based on the dynamic characterization shows a better machine stability than the pre-modernization status.

From a geometric point of view, the clearances in the kinematics of the transverse slide have been considerably reduced.

Machine tool assessment will be completed in the near future with the geometric parameters according with the ISO 230 standard [20].

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