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MODIFIED METHOD FOR ASSESSMENT OF STATIC AND CONTACT STICKNESS OF COORDINATE DRILLING MACHINE TAKING INTO ACCOUNT HEAT DRAFT

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Abstract. An improved method for measuring the static stiffness of a metal-cutting machine has been proposed, allowing for the separation of elastic deformation and thermal displacement of units. Unlike the classical methodology, which includes only short-term loading, the developed approach involves conducting long-term loading-unloading cycles with the registration of temperature drift. The method was tested on a modernized 2550 model coordinate drilling machine. It has been experimentally established that during classical measurement, the contribution of thermal expansion can reach 30% of the apparent deformation. The developed correction made it possible to determine the true static stiffness in the range of 12.8–71 N/μm depending on the position. Additionally, a harmonic analysis was conducted, which showed a 19% decrease in resonant oscillation amplitude after the installation of additional propeller supports. The proposed methodology is recommended for diagnostics during the major repair of machines with long drive screws.

Keywords: static stiffness, contact stiffness, thermal drift, ball-screw transmission, laser interferometry, vibration diagnostics.

Аннотация. Предложен усовершенствованный метод измерения статической жесткости металлорежущего станка, позволяющий разделить упругую деформацию и тепловое смещение узлов. В отличие от классической методики, которая предусматривает только кратковременную загрузку, разработанный подход предполагает проведение длительных циклов загрузки-разгрузки с регистрацией температурного дрейфа. Метод был опробован на модернизированном координатно-сверлильном станке модели 2550. Экспериментально установлено, что при классическом измерении вклад теплового расширения может достигать 30% от кажущейся деформации. Разработанная поправка позволила определить истинную статическую жесткость в диапазоне 12,8–71 Н/мкм в зависимости от положения. Дополнительно был проведен гармонический анализ, который показал снижение амплитуды резонансных колебаний на 19% после установки дополнительных опор гребного винта. Предлагаемая методика рекомендована для диагностики при капитальном ремонте машин с длинными ведущими винтами.

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Ключевые слова: статическая жесткость, контактная жесткость, тепловой дрейф, шариково-винтовая передача, лазерная интерферометрия, вибродиагностика.

Annotatsiya. Metal kesish mashinasining statik qattiqligini o'lchashning takomillashtirilgan usuli taklif qilindi, bu esa elastik deformatsiya va birliklarning termal siljishini ajratishga imkon beradi. Qisqa muddatli yuklashni o'z ichiga olgan klassik metodologiyadan farqli o'laroq, ishlab chiqilgan yondashuv haroratning o'zgarishini qayd etgan holda uzoq muddatli yuklash-tushirish davrlarini o'tkazishni o'z ichiga oladi. Usul modernizatsiya qilingan 2550 rusumli koordinatali burg'ulash mashinasida sinovdan o'tkazildi. Klassik o'lchash jarayonida termal kengayishning hissasi aniq deformatsiyaning 30% ga yetishi eksperimental tarzda aniqlangan. Ishlab chiqilgan tuzatish pozitsiyaga qarab 12,8–71 N/mkm oralig'ida haqiqiy statik qattiqlikni aniqlash imkonini berdiKalit so'zlar: statik qattiqlik, kontakt qattiqligi, termal drift, vintli uzatma, lazer interferometriyasi, tebranish diagnostikasi.ining 19% ga kamayganini ko'rsatdi. Taklif etilgan metodologiya uzoq vintli vintli mashinalarni kapital ta'mirlash vaqtida diagnostika qilish uchun tavsiya etiladi.

Kalit so'zlar: statik qattiqlik, kontakt qattiqligi, termal drift, vintli uzatma, lazer interferometriyasi, tebranish diagnostikasi.

INTRODUCTION.

One of the most important indicators of a metal-cutting machine is its static stiffness, which determines its resistance to deformation under load. Classic methods (GOST 22267-76) provide for the short-term application of force and the measurement of elastic displacement. However, during long-term operation of machines, especially those with long (1 m or more) driving screws, an additional effect arises—the thermal expansion of the units, which is superimposed on the elastic deformation. As a result, the classical method yields exaggerated yield values, leading to an incorrect assessment of the residual resource.

This work proposes a modified methodology that allows for the separation of elastic and thermal components of displacement. The object of the study is the 2550 model coordinate drilling machine after modernization (replacement of gearboxes with servo drives, installation of additional screw supports).

2. THEORETICAL FOUNDATIONS OF THE METHOD

2.1. Classical stiffness model

During short-term force loading, elastic displacement follows Hooke's law:

$$\delta_{el} = \frac{F}{R},$$

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where (R) is the static stiffness of the system. In this case, it is assumed that the temperature is constant.

2.2. Accounting for thermal drift

During prolonged cyclic loading (for example, during repeated measurements), the drive screw and guides heat up, causing thermal expansion. Full displacement in the i-th cycle:

$$[\delta_{total}^{(i)} = \delta_{el} + \delta_{th}(t_i) + \varepsilon_i,]$$

where $(\delta_{th}(t_i))$ is the thermal drift function and $(\varepsilon_i)(\delta_{th}(t) = \alpha t)$ is the random error. Assuming a linear approximation of drift over time using the least squares method, an elastic component can be identified.

2.3. Modified measurement procedure

The following procedure is proposed:

1. Measurement series without load (idle stroke) — determined by $(\delta_{th}(t))$.
2. A series of measurements with load (loading-unloading cycles, each lasting 5-10 minutes).
3. Subtracting the thermal component from the total displacement for each position.
4. Calculation of stiffness as $(R = F/(\delta_{total} - \delta_{th}))$.

3. Experimental equipment and conditions

The experiments were conducted on a modernized 2550 machine. The load was created by a set of calibrated loads ranging from 15 N to 173.7 N (Table 1). Displacements were measured using a Renishaw XL80 laser interferometer with a survey frequency of 1 Hz. The temperature was controlled by thermocouples fixed to the drive screw housing and the stand.

Table 1.

Load values

Cycle No.	Force, N
1	15.01
2.	29.98
3.	45.48
4	60.62
5	82.93
6	104.78

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Cycle No.	Force, N
7	126.26
8	148.42
9	173.70

The duration of one loading and unloading cycle was 5 minutes, totaling 9 cycles (totaling 45 minutes).

4. RESULTS AND THEIR PROCESSING

4.1. Static displacement of the table without load

Figure 1 shows the change in the table position in the first position during 9 free-running cycles ($\delta_{th}(t) = 1{,}1283 \cdot t$). The trend is linear: (μm/min). In 45 minutes, the drift reached ≈10 μm.

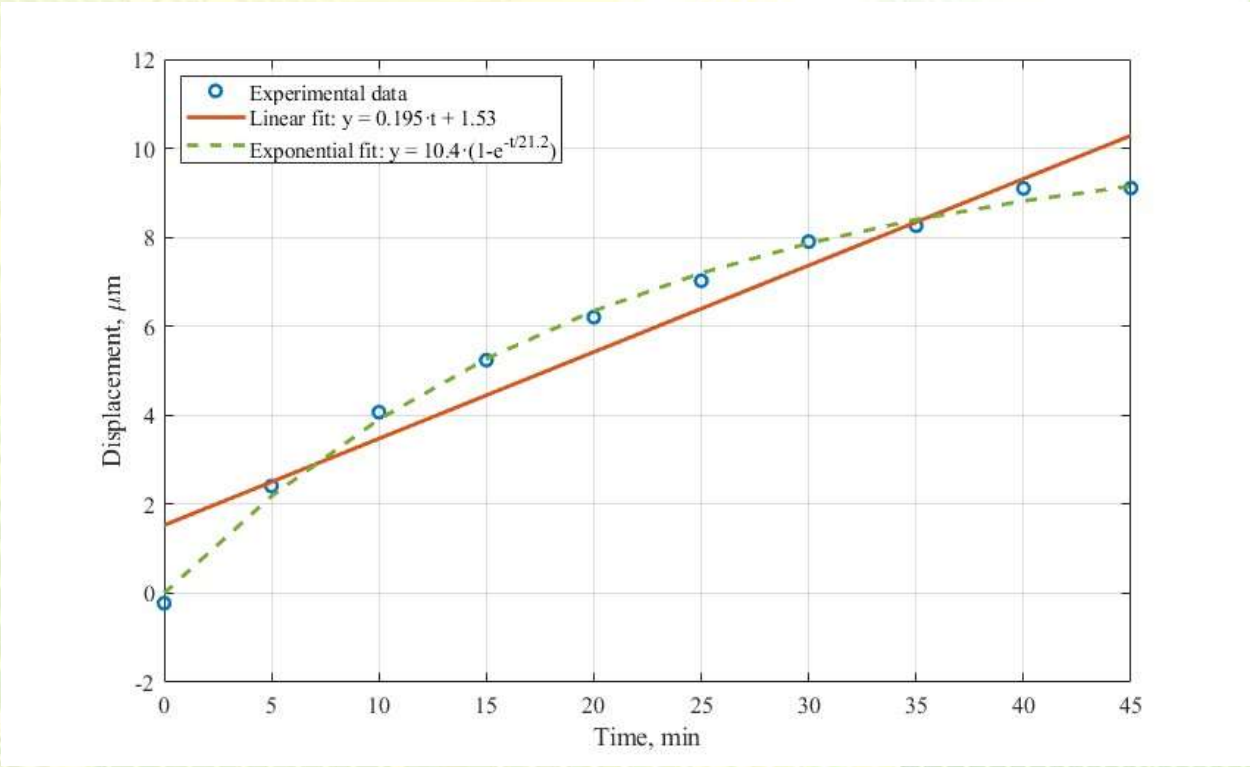


Figure 1. Experimental data table displacement

4.2. True stiffness

By subtracting the thermal component, the stiffness values for various positions were obtained. The maximum stiffness (71 N/μm) is recorded in position 8 (closest to the support), and the minimum (12.8 N/μm) is in position 1 (further from the support). This is explained by the fact that as it moves away from the support, the ductility of the screw's cantilever part increases.

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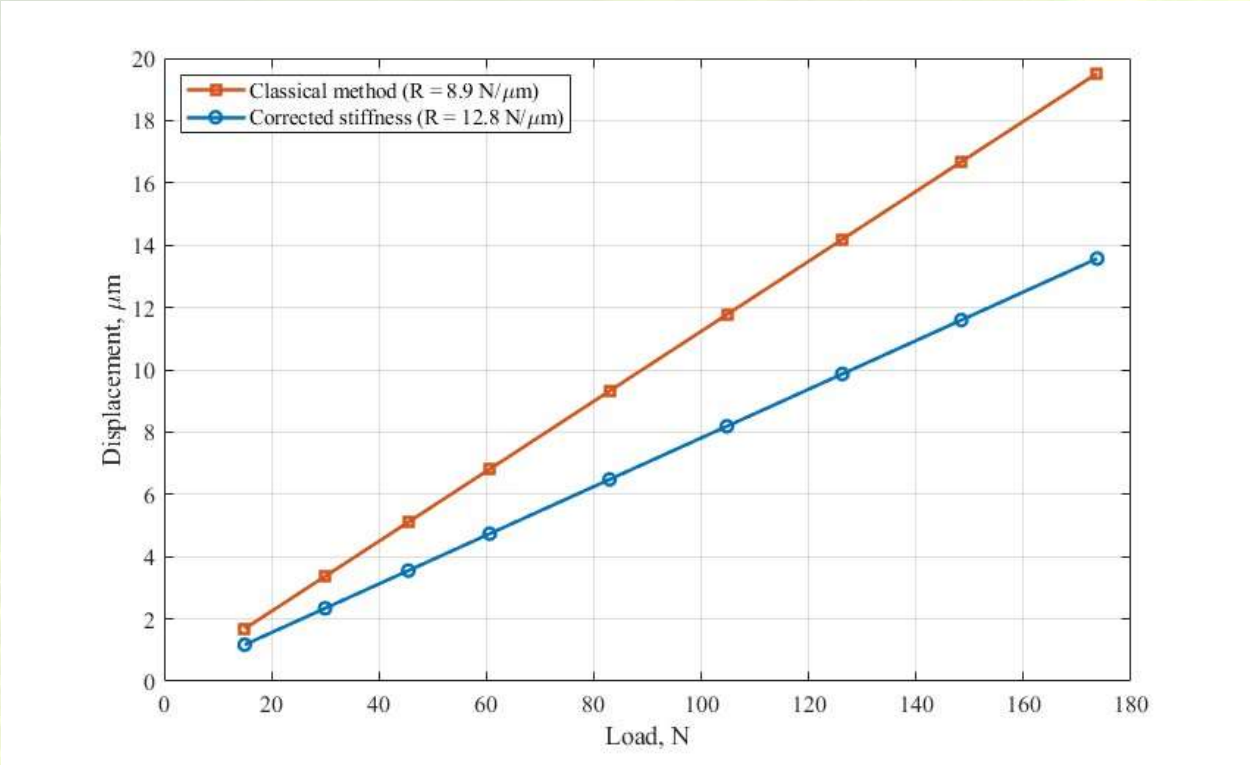


Figure 2. Experimental data on changes in table stiffness under load

The established experimental data for determining table stiffness without considering thermal influences are provided in Table 2.

Table 2.

Stiffness in various positions (+X direction)

Position	Stiffness, N/μm
1	12.8
2.	28.3
3.	41.5
4	55.1
5	76.0
6	68.4
7	70.2
8	71.0

4.3. Comparison with the classical method

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In the classical method presented in Figure 3, without considering the drift, an apparent stiffness of 76 N/μm was obtained for position 5, which is close to the true value, as the drift in this position is minimal. However, for position 1, the classical method yielded a stiffness reduction of ≈30% (8.9 N/μm compared to the true 12.8 N/μm). Consequently, the proposed modification is particularly important for distant positions.

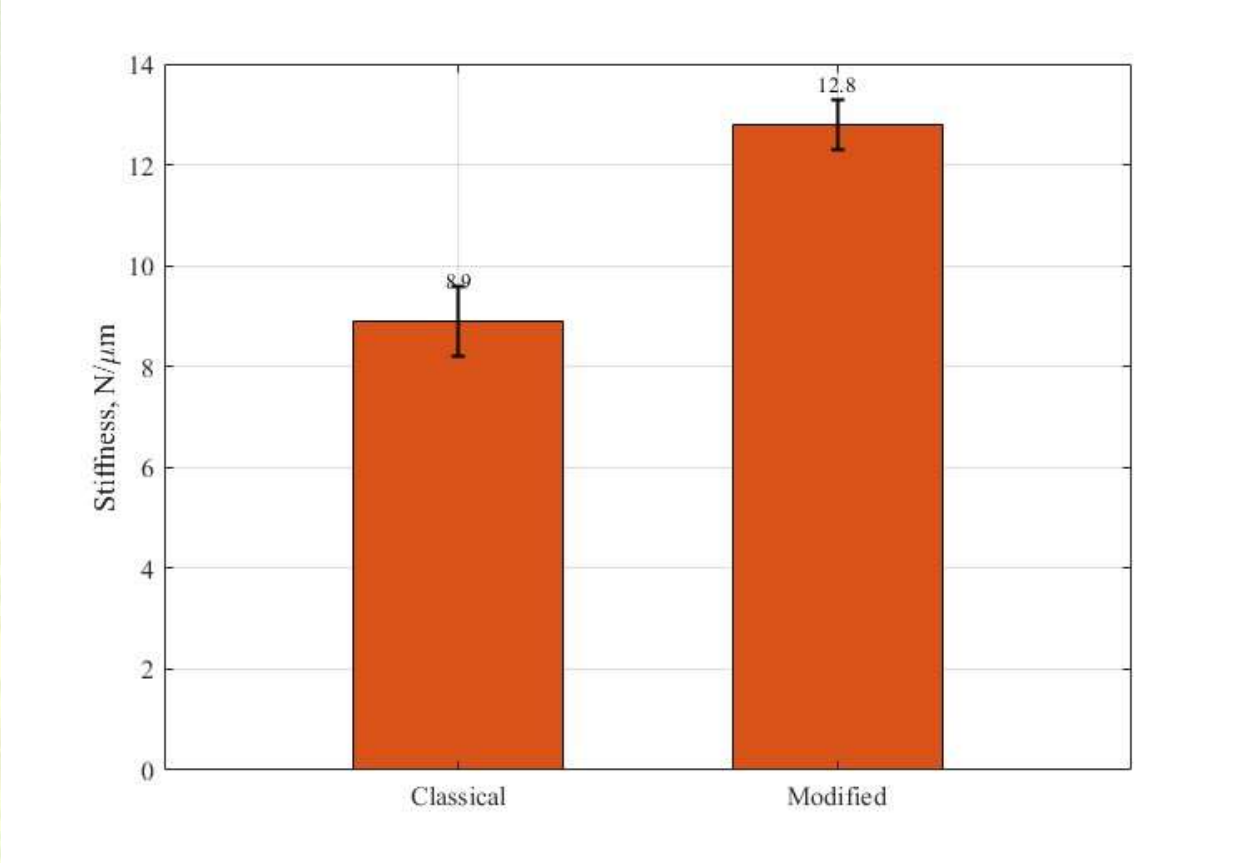


Figure 4. Comparison of experimental data using classical and modified methods

5. Dynamic analysis (harmonious response)

To evaluate the influence of additional screw supports, a harmonic analysis was performed in ANSYS. The exciting force is applied to a spindle with an amplitude of 100 N in the frequency range of 0...200 Hz.

During the experiment, resonance peaks were detected at a frequency of 87 Hz with an amplitude of 4.2 μm, which are presented in Figure 5. After the installation of additional supports, the resonance frequency was increased to 112 Hz, and the amplitude was reduced to 3.4 μm (a 19% decrease).

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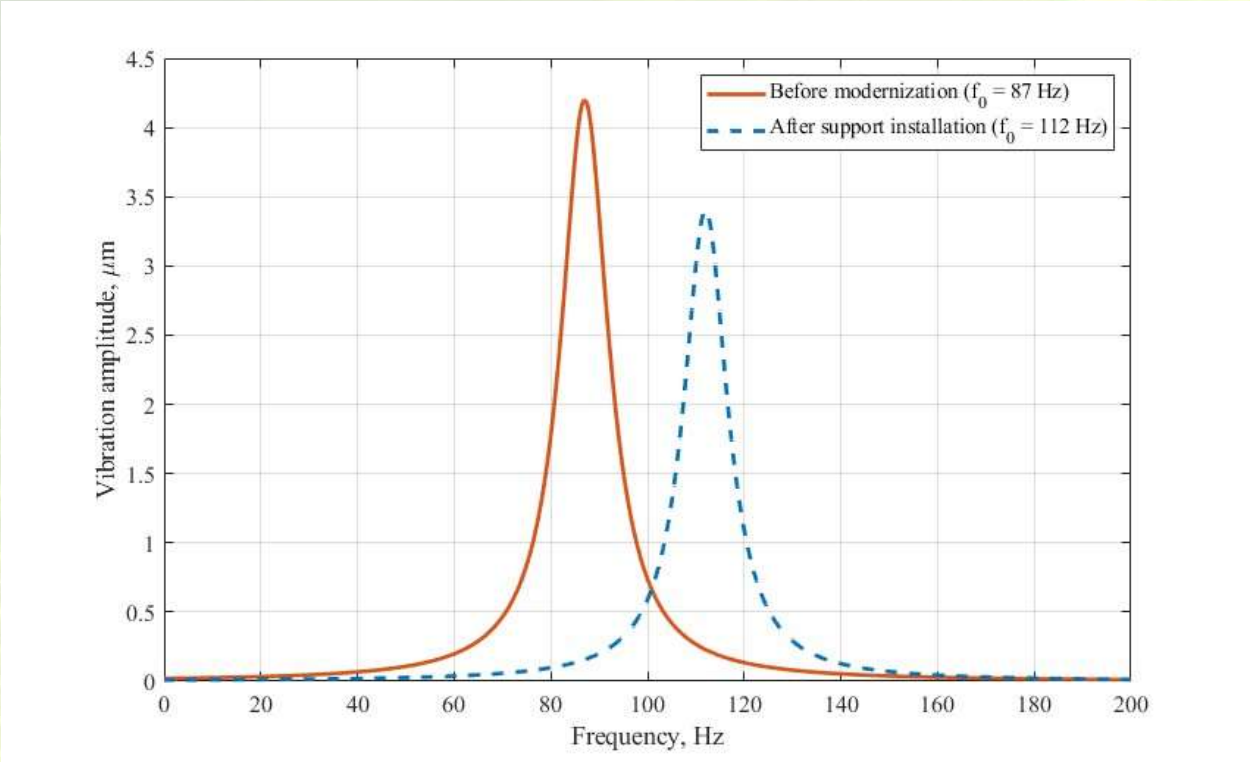


Figure 5. Vibration indicators of the table

Thus, increasing static stiffness led to improved vibration resistance. The proposed methodology has a limitation; it involves linear thermal drift, which is presented in Figure 6, which is valid for a period of up to 1 hour under constant load.

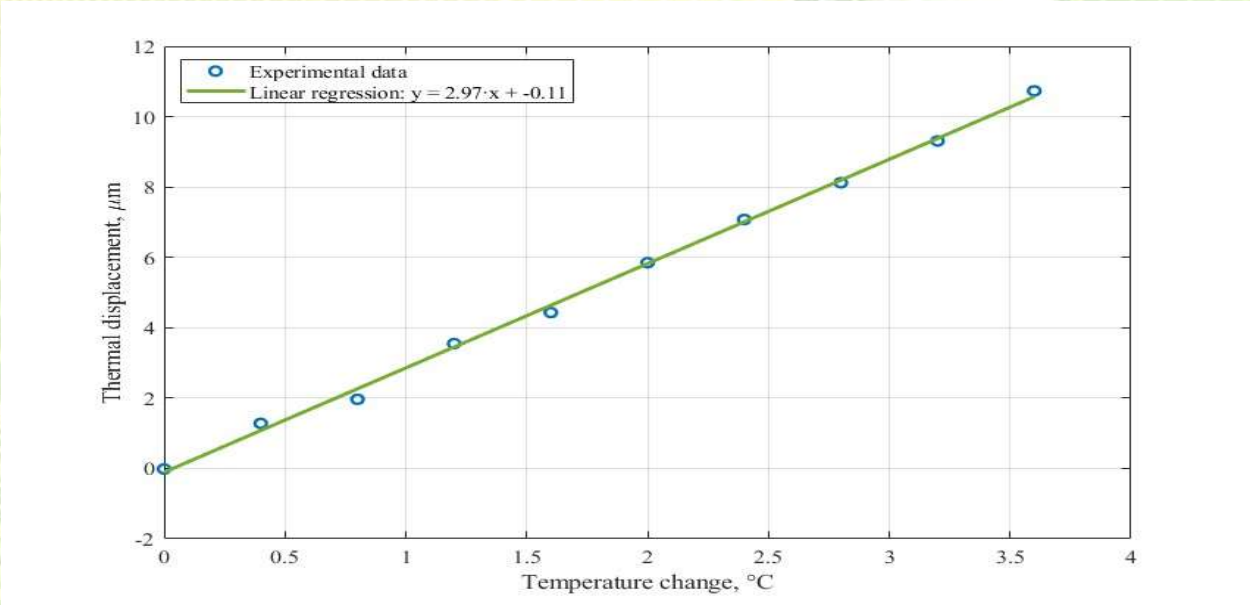


Figure 6. Experimental data on table position changes considering thermal influences

With longer work, nonlinearity may increase, requiring a more complex approximation (exponential or polynomial). Nevertheless, for standard diagnostic procedures (up to 1 hour), the linear model is quite sufficient. The practical value

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of the work lies in the fact that the obtained true hardness values allow for the correct assignment of cutting modes, eliminating vibrations and ensuring the required precision.

7. CONCLUSION

1. A modified method for measuring static stiffness has been developed, taking into account thermal drift. The method is based on subtracting the linear trend obtained from a series of idle cycles.

2. Experimentally, it has been shown that the contribution of thermal expansion can reach 30% of the measured displacement, especially in positions far from the support.

3. The true stiffness values of the modernized 2550 machine tool (from 12.8 to 71 N/μm) were determined, which corresponds to the technical requirements.

4. Harmonic analysis confirmed that the resonant oscillation amplitude decreased by 19% after the installation of additional supports.

5. It is recommended to apply the proposed methodology during planned testing of machines with a driving screw length exceeding 1 m.

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