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LINEAR AND ANGULAR MEASUREMENTS

PRECISION ROUNDNESS MEASURING GAUGE

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The main types of roundness measuring gauges used in industrial countries are considered. A mountable roundness measuring gauge made by a precision machine-tool plant in St. Petersburg is compared with those types.

Checking the accuracy of the geometric form of machine parts is one of the most complex problems in manufacturing. Statistical studies show that two-thirds of machine parts and mechanisms are solids of revolution and are used in the most crucial units and connections. The deviations of the part surfaces from the geometrically correct form that they represent in drawings significantly affect the accuracy, reliability, and durability of joined parts. The ideal form of the section of a solid of revolution in a plane perpendicular to its axis is a circle. Checking the form of a surface of rotation, therefore, comes down to measuring the roundness.

The problem of measuring the roundness of solids of revolution arises in many areas of engineering – machine tool manufacture (spindles, shafts), power equipment manufacture (turbine and generator shafts), railroad transportation (wheelset axles), metallurgy (rolling mill rolls), papermaking (calender rolls), and others. A large variety of methods and measuring machines and instruments for solving that problem are available in various countries.

Review of Existing Equipment

Stationary Measuring Instruments. Two classes of devices, stationary and nonstationary, are used to measure the roundness of parts. Stationary instruments are put in special premises on a vibration-insulated foundation. The operating principle of such instruments is based on the use of the precision rotation of a spindle, on which a linear acceleration sensor is fastened and is in contact with the part. Stationary measuring instruments can be used for high-precision measurements of almost all the geometric parameters of parts made as solids of revolution. But they do have a number of disadvantages: they cannot check the parameters of large parts (more than 1600 mm long) such as calender rolls, rolling mill rolls, etc., because a long time (20–40 mm) is required to reset the parts and adjust the instrument; only highly qualified personnel can use the instrument; the cost of the stationary instruments is very high (up to two million dollars).

The best-known manufacturer of stationary measuring instruments is Rank Taylor Hobson, which was found more than 100 years ago. Instruments made by this company are used widely.

Nonstationary Instruments. Roundness measurements of parts are made at the manufacturing and repair sites (workshop conditions) using nonstationary, portable measuring instruments. The most widely used are two types of instruments, with two-point contact (micrometers and snap gauges) and various designs of prisms with a linear displacement sensor.

In the first type are instruments for checking the form of model 05009 and 05010 rolling mill rolls made in Russia and Roll Cal instruments made by Roll Test (Finland). Two factors must be taken into account when assessing the accuracy of instruments with two-point contact in roundness measurements: first, a profile with an odd number of faces $n = 3, 5, \ldots$ has different diameters in all directions. That proposition was stated in the standard All-Union State Standard GOST 24642-8; and second, instruments with two-point contact, like micrometers, measure only diameters.

As a result, form roundness will not be detected if an instrument with two-point contact, e.g., such as the Roll Cal, is used to measure parts with a profile having faceting with an odd number of faces.

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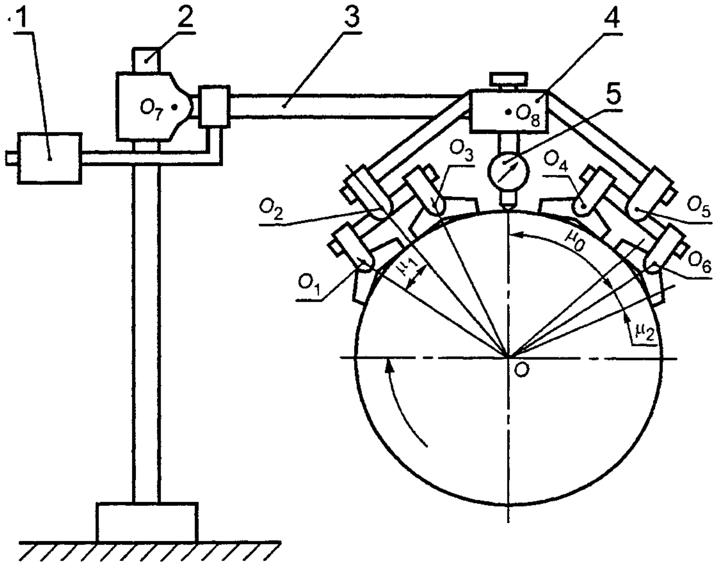

Fig. 1. Schematic of roundness gauge.

Generally, if the profile of the part is a superposition of even and odd harmonics, in roundness measurements such instruments give a large error. That is the main disadvantage of the broad class of instruments with two-point contact.

Instruments of the second type, prisms, are portable and simple to use but the error of roundness measurement on prisms is large and may reach 100% of the deviation of the profile of the part from a round shape.

Analytical Instruments. One more type of nonstationary measuring systems is based on the use of signals from sensors of small linear displacements, those sensors being placed at certain angles around rotating parts. At least three sensors should be used. The sensor signals are processed with a fairly complicated custom-made computer program. Such instruments can arbitrarily be called analytical since the mechanical part in them is reduced to a minimum (there are no rotating parts, no complex suspension mechanism, etc.) and the geometric characteristics are determined on the basis of analytical calculation on a computer. This line of instruments is still in the development stage.

Mountable Roundness Measuring Gauge with Self-Setting Multistage Supports

Schematic. A method for measuring the roundness and form of the cross-section profile of solids of revolution as well as instruments based on it have been developed in Russia and have been patented in the USA, Japan, Britain, Switzerland, and other countries, leaders in the manufacture of precision measuring instruments [1]. Those instruments, mountable roundness gauges, are on a par with devices such as prisms and indicators in regard to simplicity and convenience of use and almost as accurate as Rank Taylor Hobson measuring.

The operating principle of the mountable roundness gauge is that a system of multistage self-setting supports when interacting with the surface of a rotating part stabilizes the position of the center of the median circumference of the inspected part relative to the sensor, while displacements of the moving element (feeler) of the sensor are caused by the deviation of the inspected profile from roundness. Mountable roundness gauges can measure parts of any length with a diameter of 40 to 2000 mm or more directly on the machine tool.

The schematic of the roundness gauge is shown in Fig. 1. The roundness gauge *4* with self-setting equalizers (freely suspended at points O_1–O_6) is hinged to the arm *3* at point O_8.

The arm *3* is attached at point O_7 to the upright *2*, which is set up, e.g., on a bed, slides, or grinding wheel of a machine tool. A counterweight *1* is fastened to the arm *3* so that it can be moved along the rod of the arm.

When a measurement is to be made, the roundness gauge is lowered onto the relevant surface of the rotating shaft and is clamped to it by its self-setting supports under its own weight. All the elements of the measuring system turn freely about the axes O_1–O_8, ensuring that the support of the mountable roundness gauge is in constant contact with the shaft. The arm-hinge system of the system, having eight degrees of freedom in the plane of the profile being measured, ensures that the measuring

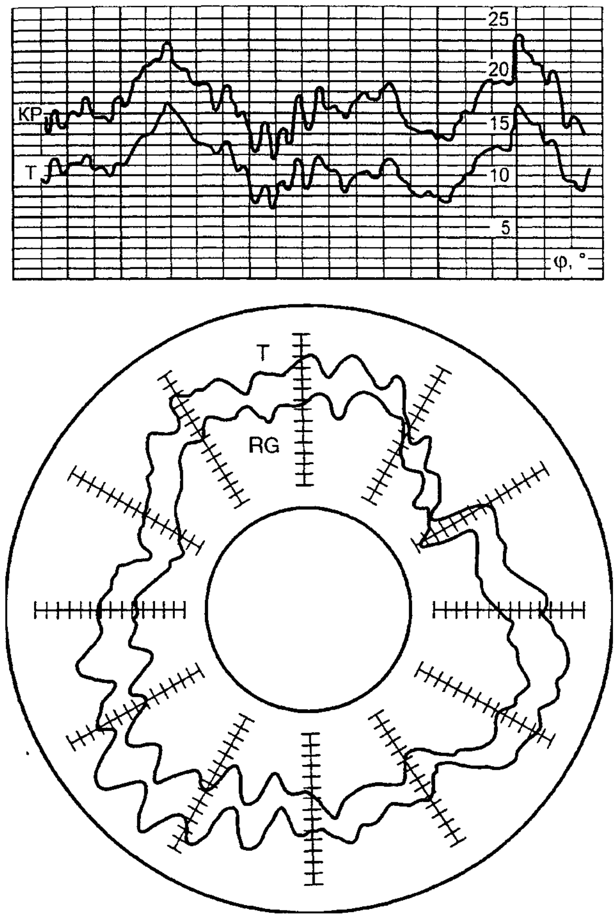

Fig. 2. Records of roundness of the same part in rectangular and polar coordinate systems.

system constantly tracks the position of the shaft; the instability of the position of point *O* of the inspected profile does not affect the indications of the linear displacement sensor *5*, which records the roundness of the reference section of the rotating shaft. The support of the roundness gauge is in contact with the shaft at points determined by given angles μ.

If the machine tool slide with the arm *2* is moved along the rotating shaft, then the taper and barrel shape can be measured in addition to the roundness of the shaft cross section.

Metrological Characteristics. The mountable roundness gauge for determining the main metrological characteristics was checked by a special method based on comparing measurements of the form of the profile with the mountable roundness gauge and the Talyrond roundness measuring instrument taken as a reference instrument. For an inspection the measuring circuits of the inspected and reference instruments were made so as to have the maximum number of elements in common in order to eliminate the influence of their error on the result of the experiment. A Talyrond electronic recording system was used for that purpose in both cases.

Figure 2 shows the records of roundness of the same part in rectangular and polar coordinate systems, obtained on the Talyrond roundness measuring instrument (curve *T*) and the mountable roundness gauge (curve *RG*). For simpler analysis and convenient comparison of the *T* and *RG* curves, the recorder pen is displaced when recording the form of the part profile. Analysis of a large number of roundness graphs of various shapes and experience gained from the use of the roundness gauge under industrial conditions have shown that the mountable roundness gauge measures deviations from roundness to within 15–18%. For example, if the deviation of a part profile from roundness is 10 μm, the error of measurement is less than 1.8 μm.

TABLE 1. Comparative Table of Technical Characteristics of Instruments

Characteristics	Company (country), name of instrument								
	Rank Taylor Hobsons (UK), Talyrond						Roll Test (Finland), Roll Call	ABRIS Company (Russia), ABRIS-KD-2 measuring system	AO "ZPS" Precision Machine-Tool Works, (Russia), mountable roundness gauge
	Models								
	30	31	32	252	262	400			
Maximum diameter of part measured, mm	200	370	370	460	460	450	1000	320	2500
Maximum mass of part measured, kg	12	12	30	20	50	225	Without limits	20	Without limits
Maximum height of part measured, mm	200	225	225	500	500	1000	Without limits	250	Without limits
Error of roundness measurement, mm	0.025 µm + 0.0005 µm/mm		0.04 µm + + 0.0003 µm/mm	0.03 µm + + 0.0003 µm/mm	0.04 µm + + 0.0003 µm/mm	0.05 µm + + 0.0003 µm/mm	Scale value 1 µm	0.05 + 1 + + 0.1A^*	0.5 + + 0.18A^*
Mass of instrument, kg	38	62	70	279	314	3500	250	100	1.2–50
Overall dimensions of instrument, mm	380 × 280	820 × 343	820 × 343	760 × 760 × × 1513	760 × 760 × × 1513	920 × 1400 × × 2310	–	540 × 320 × 700	–
Place for setting up	Special base						Lathe	Special base	Lathe
Plane of measurement	Horizontal						Vertical	Vertical	Vertical, horizontal
Cost, thousands of dollars (US)	200–600						119	–	5–40

* A – deviation of part from roundness.

Comparison with Foreign Counterparts. The characteristics of the mountable roundness gauge and those of instruments made by the best-known manufactures are compared in Table 1. Judging by the set of properties listed in Table 1 the mountable roundness gauge is "cost/quality" optimal, especially for measurements directly on machine tools in manufacturing and repair facilities. Work with the gauge does not call for highly qualified personnel or adjustment for each part and centering of the part, thus considerably saving measuring time. The high accuracy of measurement puts the mountable gauge above the competition from other instruments for various areas of application, e.g., for inspection of the form of seats for the antifriction bearings of railroad and subway wheelsets (in accordance with All-Union State Standard GOST R 50334-92 "Rolling stock axles"), which can reveal flaws, avoid increased noise, vibrations, bearing failure, and accidents.

Additional Capabilities of Mountable Roundness Gauge and Its Components

Straightness Measurement of Axes of Solids of Revolution. The updated mountable roundness gauge can check the straightness of the axis of the axle of a part during machining on a lathe and during use. The axis of the axle it taken to mean the locus of the centers of the median circumferences of the profiles of the axle cross sections.

TABLE 2. Models of Mountable Roundness Gauge Manufactured

Model	Sensor	Scale value: indicating device	Recording instrument	Data processor
1	Clock-type indicator	0.5–10	–	–
2	Inductive transducer	0.2–2	–	–
3	Inductive transducer	0.2–2	Fast recorder	–
4	Inductive transducer	Computer monitor	Printer	Computer with custom-made software

Checking that the axes are straight is important when centering axles, with outer surfaces deviating from roundness to the same order as the eccentricity of the axles and shafts (built-up shafts in shipbuilding, in large-scale electricity generation, etc.).

The mountable roundness gauge can be used to solve the problem of finding the center of gravity of the cross section of large parts with a large deviation from roundness prior to centering them and setting them up on a lathe. This operation saves metal during machining of the parts.

Increase in the Accuracy of Machining Parts on Lathes. The accuracy of machining parts depends on the error of the lathe on which the part is machined. One possible way of increasing the machining accuracy is to replace worn equipment with new. Such replacement is not always possible, however, because of the high cost of the equipment.

The multistage, self-setting supports used in the mountable roundness gauges can be employed in fundamentally new designs of devices, ensuring that the axis of rotation of parts is stabilized in three dimensions during machining in which rests with self-setting supports are employed. With those devices, the required machining accuracy of parts with any overall dimensions can be obtained without replacing the machines, merely by using a new method of basing the parts.

The AO "ZPS" Precision Machine-Tool Works has developed a two-stage approach to comprehensive solution of that problem. In the first stage, the state of the technological process of machining the parts is analyzed: flaws in the process are pinpointed, the state of the stock of machine tools is evaluated, and recommendations are made for modernization of the equipment. The instrument used for the analysis is a mountable roundness gauge and various models of it, which are easily adapted to the required conditions of the measurements. In the second stage, equipment is built for modernizing the machine tools and is assembled and installed.

Technical Parameters and Designs of Roundness Gauges

Dimensions of instruments	40–80; 80–150; 150–250; 250–400; 400–600; 600–800; 800–1000; 1000–1200 mm
Mass	1.2–50 kg
Rotary speed of part	< 2–5 rpm
Scale value of indicating device	0.1–10 μm

Various models of mountable roundness gauges are made, depending on the type and composition of the equipment in the set delivered. Table 2 lists the models of mountable roundness gauge.

Hence, in the broad spectrum of roundness measuring instruments the mountable roundness gauge is the optimal in the quality/cost respect.

The gauge combines high accuracy of profile measurement with any combination of even and odd harmonics with a capability for measuring the geometric parameters of parts of almost any mass and size right on a lathe, simple operation, and high productivity. Moreover, the roundness gauge costs less than its analogues.

A modified version of the roundness gauge can be used to check the straightness of the axis of a rotating shaft or axle. That parameter cannot be measured by any of the other instruments produced in the world and its importance in a number of practical applications is unquestionable.

A machine shop can get considerable technical and economic gain from increased accuracy of its machine tools if worn machine-tool equipment is modernized by employing a new technology for setting up workpieces on lathes by means of rests based on multi-stage self-setting supports.

One of the most promising areas of widespread use of mountable roundness gauges is rail transport, especially transport for high-speed routes, where wheelset axles of rolling stock must be subjected to working inspections under the conditions of a depot or repair shop and without requiring highly qualified personnel for the measurements.

Mountable roundness gauges for parts with a diameter of up to 1000 mm are light and portable (1.2–16 kg), and mounted on simple stands, and allow the parts to be rotated, even manually.

Equipments for machining and measuring the geometric form of solids of revolution allow one of the crucial problems of manufacturing to be solved, that is to considerably improve the quality of products, especially in plants making heavy and power equipment, as well as in machine building and other branches of industry, not only by means of renovation but also by modernization of existing equipment.

The extremely simple design, high accuracy and reliability, ease of operation for machining devices and measuring instruments, and comparatively low cost give mountable roundness gauges great potential for widespread use in industry.

REFERENCES

1. I. D. Gebel' et al., UK Patent 1387904, Instrument for Measuring the Deviation from Roundness of Normal Profiles of Parts.