CONCEPT OF A MEASURING SYSTEM FOR LARGE DIAMETERS OF BALL BEARINGS

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Abstract – The paper explains the necessity of geometrical measuring problems at production wind energy plants. The paper contains the concept and theoretical solutions of a measuring system for diameter of ball bearings. Different measuring principles were reviewed for the measuring problem and a possible solution is described. At the end the projected concept is compared with the high end and the low budget solution.

Keywords: diameter measurement, length measurement, ball bearing

1. BASIC INFORMATION AND STATE OF THE ART

In field of production and final inspection of ball bearings the measuring of geometrical quantities of every single component is very important. These large ball bearings are used in different technical applications from bottle filling plants to wind energy plants. The basic conditions of such a ball bearing are diameter (1m to 8m) and weight (up to 25 tons). The measuring of the diameter is needed because of the assembling of the inner and outer ring. Here the best matching from inner and outer has to be found, so that the optimal conditions for long life time and efficiency are given in this tolerance chain.

There are a few solutions to measure the large diameter of ball bearings. The high-end solution is to use a double sided coordinate measuring machine. An example is shown in figure 1. This solution needs special ambient conditions and long measuring time at high costs. However the measuring results are very good. As example the accuracy of measurement is specified at ±10µm at a diameter of 3m [1].

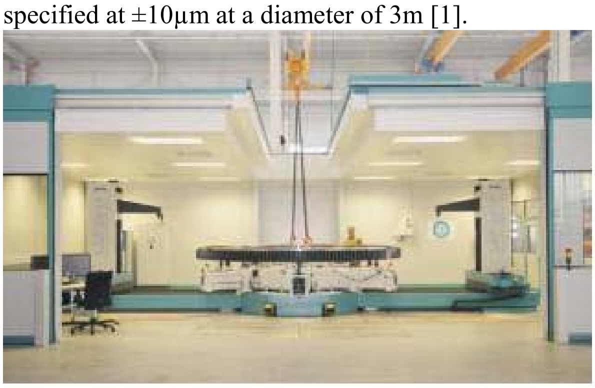

Fig. 1. Double-sided coordinate measuring machine LAFD from Wenzel Präzision GmbH [1]

Other solutions are sliding callipers and scales of length. Here influences of the factory workshop, the operator or even the applied material, like CFK or aluminium are given. There are several kinds of external interference like temperature, temperature difference and also every kind of pollution. Biggest problem is the measuring of the diameter. The diameter only is appointed by two points. In the end the measurement accuracy is much lower, but also measuring time and costs.

The new concept has to realize the following specifications:

- portable fast and repeatable measuring of the inner and outer ring of great ball bearings
- measurement range of 1 m to 8 m
- absolute error of measurement of the diameter by ±50µm
- possibility to measure under conditions of a factory workshop (dust, oil)
- calculating the diameter with more than three measuring points
- correction of the results related to the influence of temperature to measuring object and system
- measuring time lower than 20 minutes within build-up and configuration
- maximum price for sale lower than 20000 Euros

2. EXPLANATION OF THE CONCEPT AND MEASURING PRINCIPLE

At the beginning several measuring principles were reviewed. Especially optical methods like interferometry, triangulation or laser-run-time were reviewed. Every method has pros and cons to the requirements. Main problem are measuring range, measuring resolution, time per measuring position, expense for calibration and justage, environmental influences, price, complexity for hardware and software. In table I different measuring principles are shown. Measuring principles like interferometry and laser-tracer are qualified by measuring range and resolution. By the parameter justage and work safety the interferometry-principle is not acceptable. By the parameter price both systems are not acceptable. In fact no optical measuring principle was found. A new solution was found by in a tactile measuring system based on a contactless technology.

TABLE I: measuring ranges and resolution of optical measuring principles on the basis of [2]

measuring principle	vertical measuring range [m]		vertical resolution [m]
	from	to	
autofocus sensor	$10e^{-9}$	$2e^{-3}$	$10e^{-9}$
deflectometry	$0,4e^{-6}$	$20e^{-3}$	n/a
image processing	$0,1e^{-3}$	$1e^{0}$	$10e^{-9}$
photogrammetry	$1e^{-9}$	$1e^{0}$	$100e^{-3}$
interferometry (heterodyne and homodyne)	$1e^{-9}$	$100e^{0}$	$0,1e^{-9}$
lasertracer	$0,1e^{-6}$	$1e^{0}$	0,2e-6
stripe projection	$3e^{-6}$	$1e^{0}$	$5e^{-6}$
triangulation sensor	$1e^{-6}$	$1e^{0}$	$30e^{-9}$
white light interferometer	$1e^{-9}$	$3e^{-3}$	$0,1e^{-9}$

At the end a measuring component from MTS-Sensors GmbH with a magnetostriction principle was found. This measuring system has a measuring range up to 7600 mm and a resolution of 1 µm [3]. These are good preconditions, but there are problems like a hysteresis and linearity, too. Also there are constructive problems, because of the measuring range is not high enough and the temperature influences to the measuring principle and device under test.

To get the diameter of a huge ball bearing several constellations were played through. A circumcircle is defined by three points. These have the ideal positions if they are uniformly distributed. The radius of the circumcircle of a triangle (figure 2) can be calculated by formula (1) and (2).

$$r = \frac{abc}{4\sqrt{s(s-a)(s-b)(s-c)}} \tag{1}$$

$$s = u/2 = (a+b+c)/2 \tag{2}$$

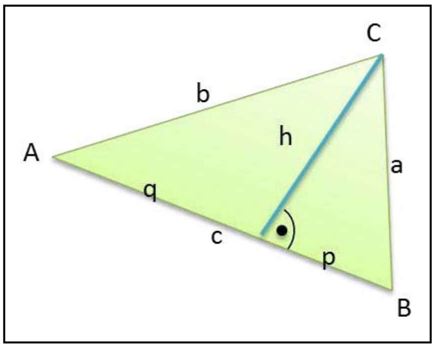

Fig. 2. Universal triangle with all angles and sides

To get a whole defined triangle several constellations are able (figure 3). The complexity of the measuring system has to be low as possible. It has to be easy to handle like sliding callipers.

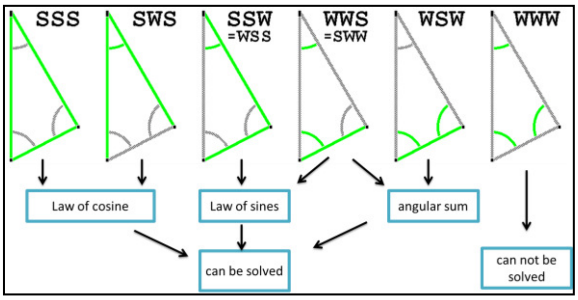

Fig. 3. Abilities universal triangle with all angles (w) and sides (s)

A measuring system was created, to reach the measuring range and the requirement of at least three measuring points a combination of two sensors was found. The solution can be seen in figure 4. The background of this composition is founded in the definition of triangles. Two length measuring sensors are in an angle of 90° arranged. One measuring system is able to detect 20 measuring positions at the same time. If every measuring system has a measuring range of 7600 mm it is possible to measure diameters up to 9600 mm.

The radius calculates by formula (1). The measuring system determines the variables p, q and h. The variables a, b and c can be calculated from the three measuring positions.

$$c = p + q \tag{3}$$

$$a = \sqrt{h^2 + q^2} \tag{4}$$

$$b = \sqrt{h^2 + p^2} \tag{5}$$

To compensate temperature and absolute accuracy several other sensors can be integrated. As example temperature sensors at the lay-on point on the ball bearing. Here the temperature of the measuring object can be detected. At the measuring system there are temperature sensors and resistance strain gauges to detect deflections.

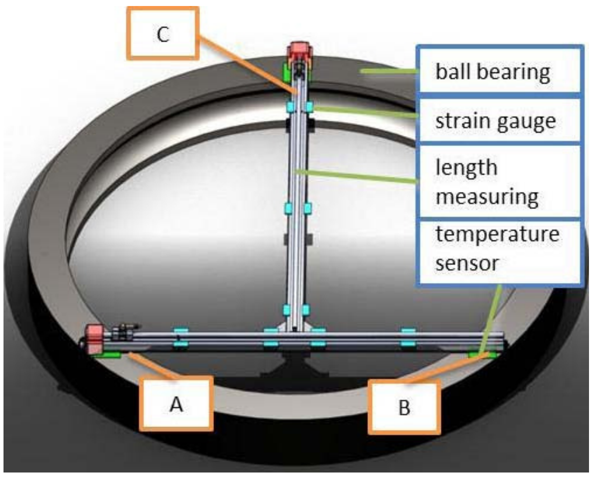

Fig. 4. Constructive concept of the measuring system with planed sensors

3. CORRECTIONS OF THE MEASURING SETUP

There are several corrections that have to be done (figure 5). The influence to the device under test is especially the change of length by temperature. The change of length of the ball bearing has to be calculated.

$$\Delta l = \alpha * \Delta T * l_0 \qquad (6)\ [4]$$

At a length of 8000mm, a ΔT of 5 K and a α of $1{,}61e^{-5}$ K^{-1} equals Δl=0,644 mm. The same calculation has to be done for the measuring system. Here Δl is a function of the measuring length.

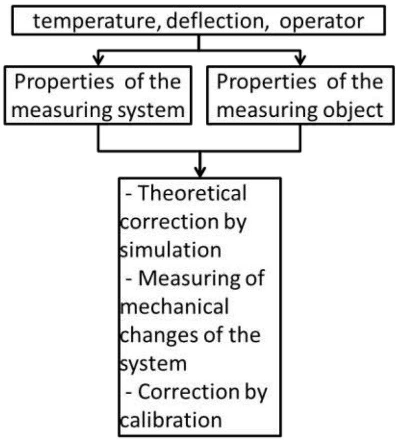

Fig. 5. Influences to the system with available correction-methods

Next to regard is the deflection of the measuring system. The measuring system can have different deflections regarding to the points of support. The deflection is a differential equation:

$$\frac{d^2 f_z}{dx^2} = \frac{M_y(x)}{EI} \qquad (7)$$

For the measuring system the exact profile, stiffness and material has to be known. As example the deflection f can be for steel and a geometrical moment of inertia:

$$f = \frac{5 * m * g * l^4}{38 * E * I * 10^7} = \frac{5 * 6 * 9{,}81 * 6000^4}{384 * 2{,}1 * 80{,}1 * 10^{12}} = 5{,}9mm \qquad (8)$$

These calculations for every part of the system and the analysis of the sensors have to be done. Other ways are shown in figure 5. Also it is possible to measure deflection by strain gauges or to calibrate all possible conditions of the measuring system. For using strain gauges the resistance has to be measured. Simplified the change of length is:

$$\frac{\Delta R}{R} = k \frac{\Delta l}{l} = k\varepsilon \qquad (9)$$

$$k = \frac{\Delta p}{p\varepsilon} + 1 + 2\mu \qquad (10)$$

4. CONCLUSION

In conclusion the concept of the measuring system is an improvement to the existing solutions. The created measuring system should be usable at conditions of laboratory and fabrication workshop. The whole system contains the possibility to measure the characteristics of the measuring object. To correct the measured values several appendages were chosen. In first practical tests only with one length measuring sensor the accuracy was shown. It was compared to a laser interferometer and an autocollimator. On the basic of this analysis the whole system has to be compared. In other practical tests the properties of the whole system and the full correction of the influences of temperature and deflection.

The founded concept seems as easy to use like sliding callipers and much cheaper like a double-sided coordinate measuring machine. The projected temperature compensation permits measuring under conditions of a factory workshop.

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