Novel multi-wave standards for the calibration of form measuring instruments

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Abstract

The calibration of form measurement instruments generally is performed by calibration standards. Current available standards are only restrictedly suited for this purpose. Therefore novel standards have been developed which embody several superimposed sinusoidal waves on a cylindrical surface. It is shown that by their application the calibration of form measurement instruments can be significantly improved.

Current calibration means for form measurement instruments

The assessment of form deviations of an industrial manufactured part depends on the proper calibration of the form measuring instrument used. Yet, in practice it turns out that numerous instruments are not properly calibrated [1].

Form measurement instruments generally are better optimised for roundness measurements than for straightness and parallelism measurements. One reason might be that rotary guides can be machined with a higher precision than linear guides. But there is also the principal argument that roundness profiles are by definition closed. Therefore several influences like thermal drift can be detected and eliminated. For the same reason fourier and filtering algorithms can be applied more easily to roundness than to straightness profiles. For the dynamic calibration of form measurement instruments it does not matter whether it is performed by roundness or straightness measurement. For all these reasons most available calibration standards for form measurement instruments are roundness standards. They can be sub-divided into near ideal geometry embodiments, like glass-hemispheres, which are applied for detecting guide errors, and sensitivity standards which may deal to calibrate the signal transmission chain. This paper deals with the latter. All existing standards are embodiments of outer surfaces.

The flick standard

There is only one type of form embodiment widely available which is applicable for the sensitivity calibration, the so-called flick standard, which is a cylinder with a flat face. Nearly all form measurement instruments are calibrated by using a flick standard. It is well known that flick standards have some major disadvantages like a small dynamical content for larger wave numbers [2]. In fact, the amplitude of the signal of a typical flick with a cylinder diameter of about 20 mm and a deepness of the flattening of 12 µm has no significant contributions from larger wave-numbers than 75 upr (undulations per revolution), which is demonstrated in fig.

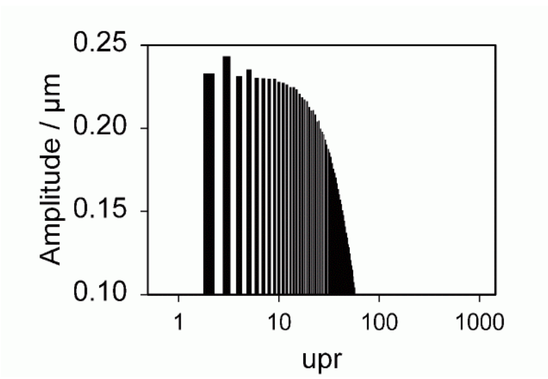

Fig.1 Amplitude spectrum of a flick

1. As all wave numbers below 75 upr contribute to the signal the individual amplitude of the wave numbers is quite low in comparison to the 12 µm form deviation. The measurement has to be performed in an appropriate measurement range for the full form deviation, but the calibration depends on the individual wave amplitudes. Such the signal to noise ratio (SNR) is quite low for flicks.

Single wave standards

There were a few tries to construct other suitable form calibration standards. One type of those experimental prototypes is a single frequency wave standard i.e. the embodiment of a single frequency sinusoidal spatial wave at the circumference of a cylinder [3]. But that type of standards cannot help either to calibrate the full signal transmission chain of a form measurement instrument because only information about a single line in the spectrum and not the full band, which is generally used for measuring form (in most cases 1-500 upr), can be derived. The SNR is optimal for single wave standards, because the full signal is carried by a single wave number.

Surface simulators

Because of the lack of appropriate form calibration standards two national metrology institutes have built up surface simulators or also called dynamic sensitivity calibrators [4,5]. These instruments can exaggerate the stylus of a form measurement instrument with arbitrary computer-controlled wave-forms. The amplitude is measured and controlled by interferometry or some other external length standard and such the deflections of the stylus can be calibrated traceable to national standards. The drawback is that those instruments are generally expensive and cannot deal as transfer standards for the industry and moreover in general do not work with rotating probe instruments.

A new approach - multi wave standards

A new form calibration standard is proposed which is a spatial embodiment of a superposition of several sinusoidal waves, the so called multi-wave standard or ”MWS”. The wave-form can for example be embodied along the circumference of a cylinder whereas the generatrices should be straight lines without form deviations to lower the influence of a possible variance of different radial sections on the results. Such type we will call the ”R”-type MWS (from ”roundness”). Please note, that the waves can be machined as well on an outer cylinder as on an inner cylinder. Therefore R-MWS are the first possible inner surface calibration standards. Another possible realisation has waves machined along the generatrices of a cylinder and nearly perfect circles as roundness profiles (”S”-type MWS, from ”straightness”). Additionally such a wave-form might be machined into a nominal flat surface and may then deal as calibration object for roughness measurement instruments.

K-space vs. real-space analysis

A new calibration procedure is proposes which not only exploits the embodied form deviation of such new type of standards, but also uses a spectral i.e. k-space-representation of the measured form profile. The amplitude spectrum of such a multi-wave standard consists of lines at the embodied frequencies with no signal for other frequencies. Fig.2 shows a typical form profile of a real R-type multi-wave standard and the corresponding amplitude spectrum. It can be seen that the spectrum is very close to the intended shape. As there are several but not too many spectral lines available, the advantages of single frequency wave standards can be combined with the advantage of surface simulators, which is broad band information. The amplitude spectrum is not sensitive to small local variations or damages because of the integrating effect of a fourier analysis.

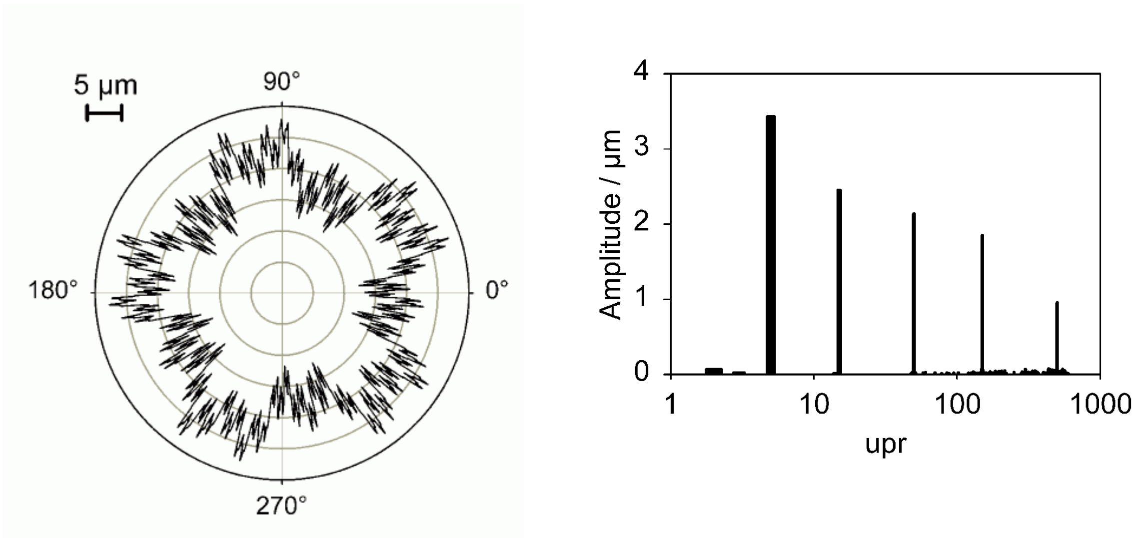

Fig. 2: Form profile and spectrum of a multi-wave standard (MWS)

Calibration by multi-wave standards

If the MWS-form is known either from a calibration certificate or by calibration by a reference instrument which in turn was calibrated by a surface simulator, it may be put to a second instrument under test and a careful measurement can be run. Guide errors or external noise sources can be detected as separate spurious peaks. Such they can also be suppressed by further processing. If the profiles shall be free from guide error influences, error-separation techniques can be applied [6]. At least three results may be read from the acquired data. The first is the overall sensitivity calibration and the second is the spectral distortion of the profile, and at last the influence of the filtering can be checked. As tests with real instruments showed, sometimes the signal transmission chain, especially the amplifier of the inductive transducer, not only distorts the amplitudes of the signal but also the phase. In principle, the phase information can also be re-constructed from the full complex fourier transform of the signal. If *P* denotes the data points of the form profile, then let *F*(*P*) be the complex fourier transform of *P*. Amplitudes and phases can be derived from *F*(*P*). Phase data analysis can help to solve problems with the angular division or variations of the angular frequency of the rotary table or spindle may be analysed.

Fig.3 Photograph of a PTB multi-wave standard. The waves are found on the ”belt”.

Realisation of multi-wave standards

Several MWS of the R-type have been manufactured by single diamond turning combined with a fast tool servo (by Institute for Production Technology, Aachen) and by ultra-precision milling (by ultra-machining workshop in PTB). Their body consists of aluminium with a chemically applied hard nickel layer on it. The waves are machined into this nickel layer. A reference mark denotes the 0°-position. The embodied wave-lengths were chosen to match the limit wave-numbers of the filters defined in written standards for form measurement [7] (i.e. (5), 15, 50, 150, 500 upr). Inner and outer surface standards were manufactured. The diameter amounts to approx. 80 mm. In fig.3 a photograph of an outer surface MWS is presented.

Conclusion and outlook

A comparison of a classical flick-based calibration of a form measuring instrument with a new calibration procedure using a multi-wave standard and integrating frequency-space analysis shows a much higher stability of the new procedure. This means a better transfer stability of the calibration value to the end-user.

These advantages together with estimated moderate (flick comparable) small series production costs of such multi-wave standards may help to spread them fast in the industry and will consequently improve the calibration quality of form measurement instruments.

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