THE INFLUENCE OF STRATEGIC PARAMETERS ON ROUNDNESS ACCURACY DEVELOPMENT

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Abstract:

Roundness is an essential geometrical feature in precision engineering metrology especially for quality control of the rotating parts. Talyrond machine becomes one of the main instruments in roundness measurement. Talyrond HPR TR-73 fitting software data analysis can contribute significantly on the measurement accuracy. The error characterization of TR-73 software is very important to find an optimum fitting solution in measurement. The final accuracy of an object is influence by many different parameters.

In this paper, the impact of fitting strategic parameters as computational geometric techniques in roundness metrology using TR-73 machine have been studied. Strategically geometric ten parameters included two types of fitting filters and four types of software algorithm techniques during four ranges of spectral wave numbers have been estimated experimentally and discussed in details. The experiments have been performed to establish reference data sets of roundness measurements for circular, cylindrical and spherical objects. Measurement results revealed that the accuracy of the maximum roundness have been improved using MZ fitting technique. Moreover, the average of roundness measurement became more accurate by about 65.6% and 57.3% using 2CR and Gaussian strategy respectively, which proved the effectiveness within application range. Thus, establishing references data sets are presented to help the designer and operator to satisfy the best fit for roundness error measurements in nano-scale metrology.

Keywords: Surface geometry, circle feature, roundness, fitting parameters and development.

1. INTRODUCTION

Roundness is the very important feature in the quality control of mechanical products for the dynamic parts that need accurate and precise measurement. Roundness is sometimes called circularity. The importance of study roundness form deviation of circle and cylindrical feature is to avoid the excessive lateral or axial runout deviation of the rotating and reciprocating parts during dynamic operation. After production procedures, manufacturing metrology of roundness feature can be done using advanced measuring instruments. Roundness geometrical machine describes the condition on a surface of revolution where all points of the surface intersected.

Historically, roundness measurement was based on the use of some simple tools such as dial indicator. While after the industrial revolution appeared the roundness measuring instruments that based on using one of two types of machines. The first one is called Talyrond machine. While another way to measure surface roundness is to use a coordinate measuring machine (CMM). The roundness measurement using Talyrond instrument based on one of two versions types of configuration. The configurations of Talyrond technique have either rotating table or rotating spindle (hydrostatic). The most common type is the hydrostatic spindle configuration version. The rotating pick-up version of the instrument was first made; this was termed 'Talyrond-1' which developed later. The Ultra high precision instrument as Talyrond HPR (TR-73) machine becomes one of the important tool in precision engineering metrology. The standard TR-73 has three accurate orthogonal axes and it equipped with high sensitive touch probe. The TR-73 probe cantilever is brought into contact with the inner or outer circular surface of object being measured at a recorded position. In the measurement operation, the probe stylus profile senses the surface height through mechanical contact, while the stylus traverses the peaks and valleys of the surface with very small contacting force. The horizontal motion of the stylus tip is converted to an electrical signal by a transducer. A number of points are taken around the component and these are then combined in computer software to determine the accurate roundness profile of the object, which represents the actual surface profile. Therefore, the Talyrond stylus system is directly sensitive to surface height with little interference.

The deviation in roundness metrology using TR-73 instrument can be related to the performance and experience of operator, environmental interaction, workpiece finishing and accuracy of software certainly. It can be assumed that some influence parameters of operator behavior and TR-73 software strategy techniques have effective reactions on the measurement quality assurance [1-2]. The measurement accuracy of a work piece influences by many different metrological parameters. The error characteristics in the TR-73 software are very important from the metrological point of view to find an optimum fitting solution. The TR-73 software data analysis can contribute significantly to the roundness measurement accuracy of measured object.

This paper presents current work to develop a testing algorithm and evaluation program as a metrological strategy for roundness measurement. In this work program, the fitting software techniques, equipped with ten different strategy parameters using TR-73 machine are studied experimentally. These parameters included two types of fitting filters and four types of software algorithm techniques during four ranges of spectral wave numbers using undulations per revolution (upr) have been studied and discussed in details. This work program will be available as an activity provided by the National Institute for Standards (NIS), Egypt. The main objective is to eliminate the reputable errors in turning operator during measurement because they direct impact in form metrology. The goal is to reduce costs according to consuming measurement time and improve figure accuracy of visible roundness measurement. Consequently, the advantage of the research is to help the TR-73 operator in the developing a methodology for precision assembly as well as an error compensation methods to improve the overall accuracy. This study is very important for the TR-73 software designer to develop new version of precision machines. Really, this research conformed that the Talyrond-73 device as an ultra high precision machine is a powerful tool for roundness form metrology in modern engineering industries [3].

2. BACKGROUND AND MOTIVATION

Great benefits of manmade have been achieved from alphabet to wheel invention passing rotating parts. The final quality of an engineering rotating product as used in airplane and motor vehicle is influenced by many different factors [2-4]. The required tolerances for dynamic rotating parts continuously have to be very fine, whereas the complexity of work pieces increases. While, the selected technique for measurement have to be applied in order to achieve precision measurements and sufficient accurate results. The measurement quality of TR-73 instrument can be resultant related to the operator behavior, environmental interaction, work piece finishing, and the machine accuracy. It can be assume that some influence factors of operator behavior and TR-73 machine software accuracy have effective reactions on the measurement quality. There are two disadvantages of the stylus instruments that the probe tip may damage the scanned surface (depending on the hardness of the surface relative to the stylus normal force) and the stylus tip size [3]. Wherefore, distinguish of Talyrond TR-73 machine that the force of touch probe tip to the sample surface is very small up to less than one Newton. Moreover, the author et al. and other researchers find, it is difficult to separate the error resulting from the stylus

vibration and the result of measured surface in roundness measurement [4-6].

Roundness feature means the change in radius of object and usually referred to as "circularity" or "out-of-roundness". The measure of roundness is expressed as the difference between the smallest and largest diameters which can be expressed by peak and valley in metrology. To assist this measurement, a mathematical reference circle is used through machine software. The position of the reference circle to the measured profile and its center are not arbitrary, and should be selected by the metrology engineer to ensure the measurement result that meets required specifications [7]. The software package of Talyrond machine includes specific important strategical techniques of measurement can be used in roundness assessment.

2.1. Fitting Filters

Other important parameter in the TR-37 machine during measurement is the fitting filters. Generally, fitting filters are used to separate the number of lobes exiting a component's of measured surface. These use to eliminate sources of error and an attempt to avoid one or more reasons like swarf machining. It also uses to remove the unwanted noise signal from the measurement results. Noise often results from vibration dynamics in the machining process and from other processes or from the measurement instrument itself. Moreover, filters are used for separate low-frequency from high-frequency data signals to simplifying the evaluation of measurement results. Filters are also used for separate different lobbing frequencies to evaluate the process and to assure highly reliable measuring results.

2.2. Fitting Spectral Wave Responses

Other important parameter in the TR-37 machine based on the operator use is the suitable selection of spectral wave numbers in measurement strategy. The frequently undulations per revolutions are the number of surface-profile deviations from a true circle in one revolution. Electronic filters, with different frequency responses of spectral waves are used to evaluate the surface profile. Standard filter responses are used in the rages of 1 to 15, 1 to 50, 1 to 150, and 1 to 500 upr. Fig.1 illustrates the electronic ranges of fitting filters with varying frequency responses are used to evaluate the roundness feature in measurement. For example, a 1 to 50 filter removes undulations above 50 per revolution from the measured feature profile. Without filtering, the high frequency waves can make evaluating the out-of-roundness difficult because they can conceal the lower frequencies. Often the low-frequency waves are of larger amplitude and thus of greater importance to the manufacturer.
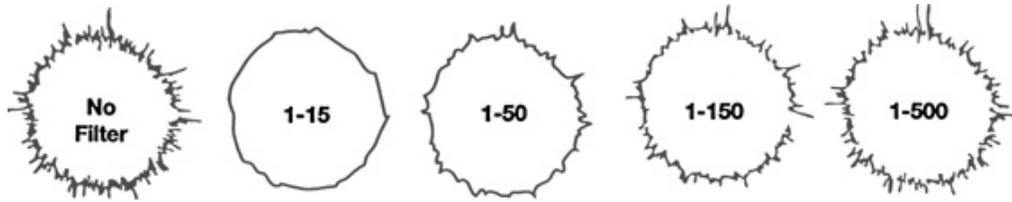
Fig. 1: Electronic ranges of fitting spectra wave numbers responses in the roundness profile.
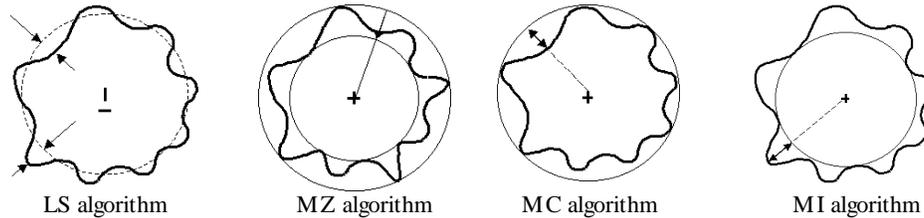

LS algorithm   MZ algorithm   MC algorithm   MI algorithm

Fig. 2: Reference software fitting circles used in roundness measurement

2.3. Fitting Algorithms

Fitting algorithm is one of the most important themes in modern dimensional metrology machines. Fitting algorithm software is particularly true of coordinate measurement systems such as CMMs and Talyrond machine. It works based on computations and convert the collected raw data to report results can be a major source of error in measurement techniques. The role of geometric fitting for roundness feature is to reduce measured point coordinates to curve and surface parameters. The resulting curves of surface are called the substitute geometry for the roundness measurement. In further processing, the computed parameters are compared to the tolerance limits for the measured part. Thus, it was found that the error estimation of the computed substitute geometry is important to determine the quality of a measurement. There is no obligatory standard or accepted method for evaluating the effects of fitting software on the error estimation for Talyrond measurements. ISO/TS 12181-1 and 12181-2 standard defines four mean specific reference fitting software methods [8-9]. Fig.2 shows the basic idea of four internationally defined fitting algorithm techniques of circles that used in roundness measurement in NMIs and industry today [2, 10]. Least square circle (LS) is well-suited for establishing a datum axis; maximum inscribed circle (MI) is the largest true circle that will fit inside the measured profile; minimum circumscribed circle (MC) is the smallest true circle that will contain the measured profile; and minimum zone circles (MZ) are two concentric circles having the same center, which enclose the measured profile and have a minimum radial separation.

2.4. Types of Errors

In fact, machined engineering surface not have perfect form due to various error sources such as machining process, finishing quality. Aaddition parameters likes measuring instrument accuracy and strategy of measurement besides human and environmental conditions are common types affecting the result of measurement errors. The purpose of TR-73 fitting software strategy is to determine the final fine feature of the object. There are many different sources of errors which may influence roundness measurements [11-15]. Some typical sources of these errors are hysteresis sensitivity, probe tip size, contacting force, spindle motions (axial, radial and tilt), alignment of artifact, thermal drift, closing error, electrical noise, mechanical vibration and work-piece contamination [16-17]. The standard uncertainty budget of a roundness measurement using TR-73 instrument has been estimated within 1.3 nm [12]. Another research work estimates the combined uncertainty in measurement at 95% certainty to be 8.01 nm [13]. Consequently, in this work, the sources of roundness errors will be study and analyze to avoid two main practical errors in measurement which called *instrumentation error* and *human error*. These two common types of errors with some others exist in all real measurement scenarios. The *error* at use *instrumentation* generates when data points are collected due to scanning of an object surface. TR-73 hardware adaptation induces different sources of error based on spindle error, probe system and transmutation system imperfections led to some inaccuracies in the measured points. Measurement error in the measuring process comes mainly from curve fit and computational resolution based on software adaptation. The *human error* arises when the operator prefers impossible strategic parameters in measurement of an object. Therefore, TR-73 operator skills and behaviors have a direct significant effect on the roundness error in future measurement. Through this research will provide an analytical study to avoid the sources of errors which have direct impact on form metrology in order to improve the quality of roundness accuracy in measurement method.

3. EXPERIMENTAL WORK

Evaluation of the Talyrond HPR fitting software strategies through sample carrying out signals has been
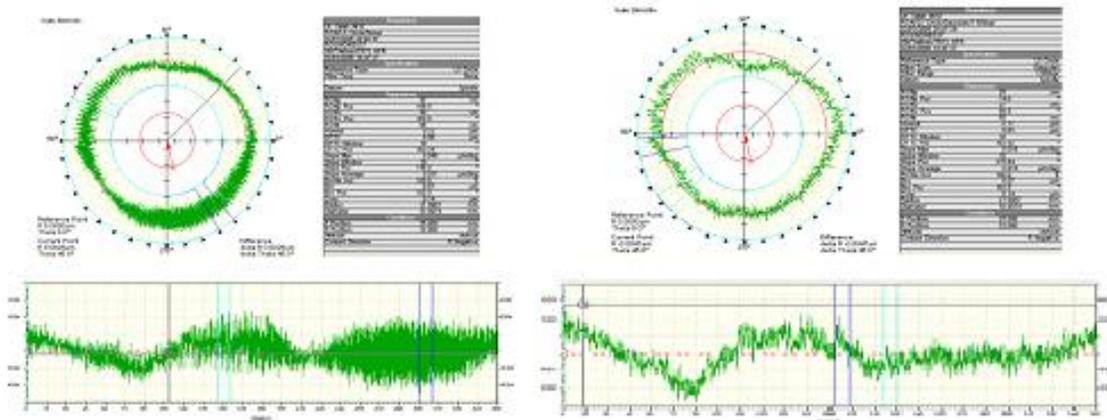
performed experimentally. The measurement evaluation process includes four basic steps of the instrumentation system: experimental verification of stylus contact, a data generator, reference algorithm, and a comparator to analyze and interpret the monitoring results. The TR-73 strategies in measurement have two types of fitting filters and four fitting algorithm categories at different four spectral wave responses. The software filters types were Gaussian and 2CR filters for data facilitation of circular, spherical and cylindrical measurements. The software fitting algorithm techniques of roundness form measurement were Least Square (LS), Minimum Zone (MZ), Minimum Circumscribed (MC) and Maximum Inscribed (MI) technique have been used. While the response of spectral wave numbers of machine software includes dominant harmonics wave range from 1-15, 1-50, 1-150 to 1-500 upr have been used. The machine software strategy and stylus scanning speed were selected and primary tested in the recommended environmental conditions. Centering object seat on machine table base was finally cleaned and located on the test position. The measured object is standard accurate cylindrical circular surface. The TR-73 machine was turned on to check the electric power switches, hydrostatic-bearing spindle rotation, and stylus speed, where a Hatchet styles tip of the long type has been selected and calibrated according to the machine working manual.

The performance of the TR-73 accuracy in scanning measuring mode has been verified and accepted within standard specification according to ISO/TS 12181-1/2 [8-9].

An inspection of cylinder feature consists of surface elements is measured and presented. In order to determine the approximation accuracy of the fitting algorithms as a geometrical form have been created. Relevant influences in the roundness accuracy measurement have been taken into account according to standards. The development of software analysis tools for fitting strategy parameters and their validation is another major challenge in this work. The specification of measuring conditions, used stylus and TR-73 test machine are presented in Table 1. Figure 3 illustrates the typical monitoring storage results of roundness measurement using datum spindle. The preliminary result shows that the roundness measurement in Fig.3b is substantially enhanced compared with that shown in Fig.3a, due to fitting strategy parameters.

Table 1: Data specification of TR-73 machine and stylus

Software code no.	: M 112/2266-02
Measurement direction	: Anti-clockwise
Attitude	: Vertical
Stylus no.	: K42/3827 TR73 1.27 mm Hatchet
Measurement speed	: 6.0 rpm
Angle range trace	: 360°

(a) Roundness measurement with non-filter   (b) Roundness measurement using Gaussian filter
Fig. 3: Typical result of roundness measurement before and after fitting parameter using TR-73 instrument.

Experimentally, the procedures of roundness feature measurement, the software filters, circle fitting techniques and spectral wave numbers have been studied of each strategy in measurement. Determination of roundness errors has been studied to differentiate the deviations between the evaluated parameters of the all fitting software strategies. The analysis of roundness measurement accuracy in this research has been investigated to predict the effect of spectral wave numbers at different specific software parameters of measurement strategy as follows:
  - Roundness measurement at different two fitting filters.

  - Roundness measurement at different four fitting techniques with Gaussian filter.
  - Roundness measurement at different four fitting technique with 2CR filter.

4. RESULTS AND DISCUSSION

4.1. The Effect of Fitting Filters

Peak and valley signals (RON_P; RON_V) in roundness metrology are the basic role to study the total error of signal profile. The total measurement error of roundness (RON_t) is the distance of a form profile between highest peak-to-valley response signals. The effects of computational

geometric software fitting filters on the roundness feature errors have been measured. Thus, depending on the separation process of signals that has been installed using LS fitting algorithm technique in the rest of the roundness measurements. The effects of two types of software filters on the peak and valley signals have been tabulated in Table 2 to compare the deviations in measurement accuracy. Fig. 4a shows the effect of Gaussian-, 2CR- and None-filter on the peak and valley response using LS fitting algorithm at different spectral wave numbers. It illustrated that, whenever increased spectral wave numbers in measurement, the error in roundness measurement increases for each filter. While the RON_t response not exceed 49 nm despite a change of spectral wave numbers when the filters are not used. Therefore, the results using LS fitting algorithm confirms that the use of the Gaussian filter gives minimum error response in roundness measurement within application range.

Table 2: Roundness measurement errors of fitting filters at LS algorithm technique

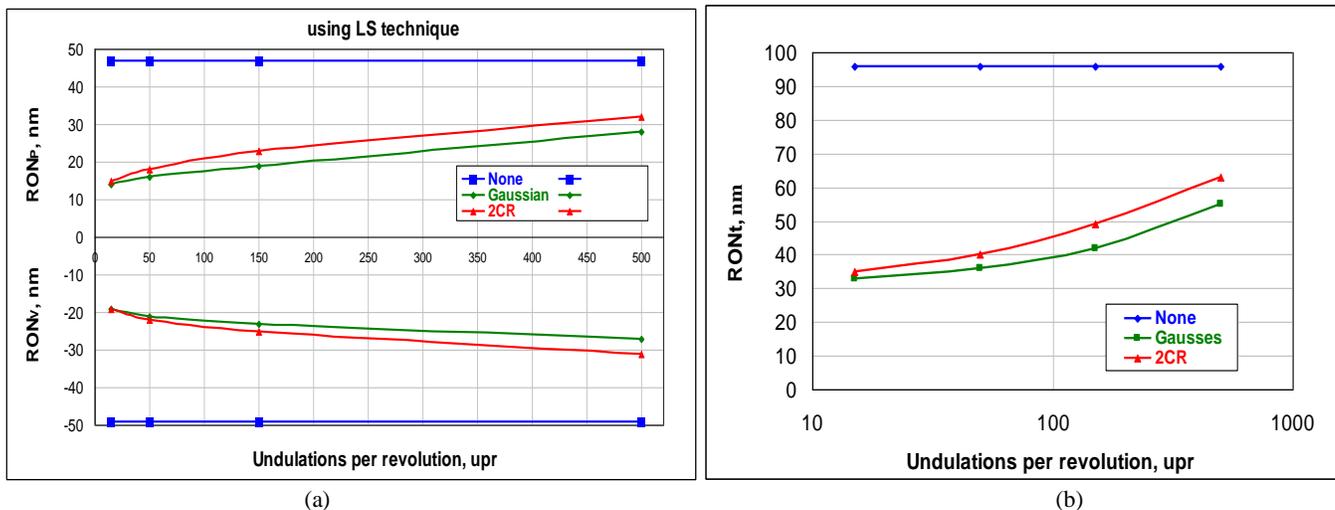| Frequency	Peak roundness error, RON_P (nm)			Valley roundness error, RON_v (nm)		
	None	Gaussian	2 CR	None	Gaussian	2 CR
1-500		28	32		27	31
1-150	47	19	23	49	23	25
1-50		16	18		21	22
1-15		14	15		19	19

(a)　　　　　　　　　　　　　　　　　　　　(b)

Fig. 4: The influence of spectral wave numbers using Gauss-, 2CR- and None-filter at (a) RON_P; RON_V and (b) RON_t.

Figure 4b shows the effect of computed software filtering on the RON_t output signals using Gaussian-, 2CR- and None-filters at spectral wave numbers changes with fixing LS fitting algorithm. It noticeable that, with upr increased, the RON_t increases using each filter. While the roundness total error is almost constant despites a change upr if not-use any filter (blue). The analysis of results confirmed that, the use of the Gaussian filter gives lowest error of RON_t measurement at the same conditions. While the impact of fitting filters and fitting techniques on roundness accuracy development still needs more analysis to establish reference data set in these measurements.

4.2. The Effect of Gaussian Filter and Fitting Techniques

Because the error response signal using Gaussian filter has lowest computational geometric error in roundness measurement when using 2CR filter, Fig. 4. This guides the author to install Gaussian filter in the next measurements during this section. Therefore, the computational effect of Gaussian filter on the roundness feature signal at different types of fitting techniques has been measured. The cleared output of Gaussian filter response in the peak and valley (RON_P; RON_V) signals have been measured and registered in Table 3. Figure 5 shows the impact of Gaussian filter on the peak and valley signals of roundness error responses using four fitting algorithm techniques at upr changes. It illustrated that, the increased of spectral wave numbers leads to increase the error in measurement for both peak and valley in each fitting. While the peak and valley error of roundness profile almost constant despite a change upr if not use any filter. It confirms that, the use of the MC fitting technique at Gaussian filter response gives lower error in the peak roundness measurement at the certain conditions. While using the MI technique at Gaussian filter response gives lower error in the valley roundness measurement in the certain conditions.

The computation effects of Gaussian filter on the total errors (RON_t) have been registered in Table 4 as seen graphically in Fig.6. It shows that the minimum geometric error was at using MZ technique, while the maximum response was at using MC technique in measurement. Therefore, the results illustrated that, if the metrologest select the MZ fitting algorithm as seen in the Fig.6, the use of the Gaussian filter response gives lowest error in the roundness measurement at the certain conditions. These results will be a gide for the metrologest at using Talyrond HPR Machine.

Table 3: The roundness errors (nm) using Gaussian filter type at various algorithms

Frequency	Peak roundness error, RON_P (nm)				Valley roundness error, RON_v (nm)			
	LS	MZ	MC	MI	LS	MZ	MC	MI
500	28	24	1	51	27	24	66	1
150	19	18	1	38	23	19	51	0
50	16	15	1	36	21	17	45	1
15	14	13	1	27	19	14	40	0

Table 4: Total error form of roundness with various algorithms at Gaussian fitting type.

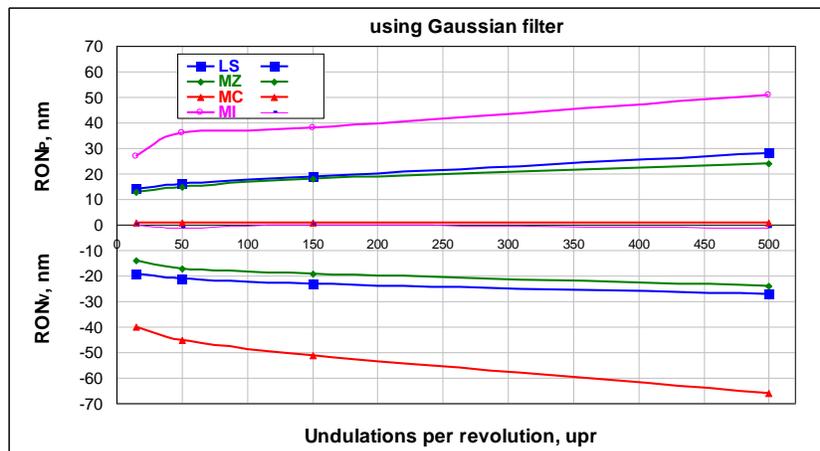| Frequency	Total error of roundness, RON_t (nm)			
	LS	MZ	MC	MI
500	55	48	67	52
150	42	37	52	38
50	36	32	46	37
15	33	27	41	27

Fig. 5: The influence of spectral wave numbers on the roundness error at various algorithm techniques.
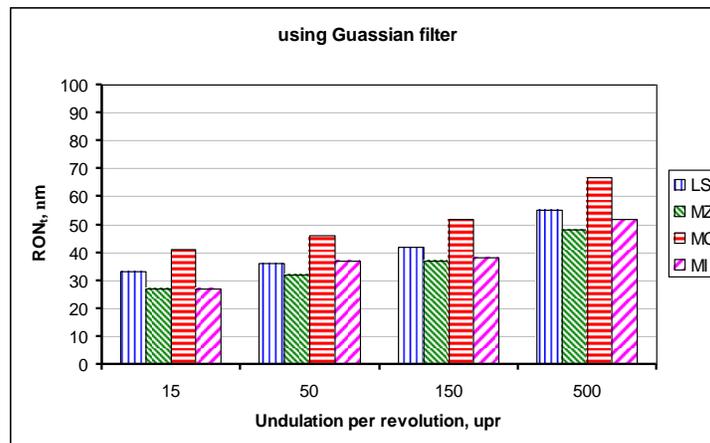

Fig. 6: Total error of roundness for various algorithm techniques at different spectral wave numbers

4.3. The Effect of 2CR Filter and Fitting Techniques

The peak and valley signals and total computed error in roundness feature profile using 2CR filter response have been measured and registered in Tables 5 and 6. It is clear that, at using the MC technique with 2CR filter response, gives lower error in the peak signal. While using the MI technique gives lower error in the valley roundness measurement. But, the lower error in the total roundness measurement was at MZ fitting technique in the certain conditions.

Figure 7 shows the influence of 2CR filter response on the peak and valley signals of roundness error using four fitting algorithm at spectral wave numbers changes. It

illustrated that, any increasing of frequency leads to increase in the roundness error in both peak and valley in each fitting. The minimum computational error of geometric measurement was MZ technique, while the maximum response technique was MC in both peak and valley positions in roundness measurement. Thus, can say, if the metrologest select the MZ fitting algorithm technique as seen in the Fig.8, it confirms that the use of the 2CR filter gives lower computational error in the roundness measurement at the same conditions. This result helps the metrologest for using the suitable reference data set for circular measurement using 2CR fitting technique on Talyrond HPR Machine.

Table 5: Roundness errors at various fitting algorithms using 2CR fitting type

Frequency	Peak roundness error, RON_P (nm)				Valley roundness error, RON_v (nm)			
	LS	MZ	MC	MI	LS	MZ	MC	MI
500	32	30	2	68	31	30	68	0
150	23	21	0	44	25	21	59	0
50	18	17	1	35	22	17	48	2
15	15	15	1	29	19	15	42	0

Table 6: Total roundness value (nm) with four fitting algorithms at 2CR filter type.

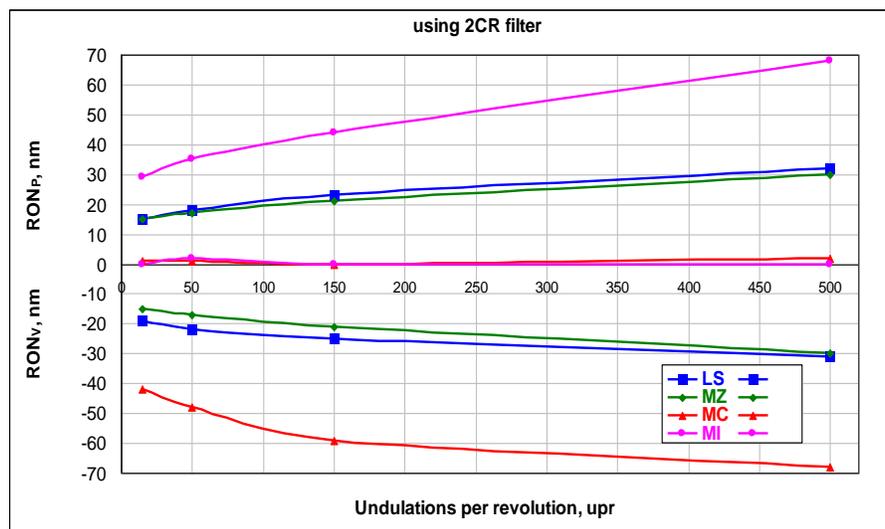| Frequency	Total error of roundness, RON_t (nm)			
	LS	MZ	MC	MI
500	63	61	70	68
150	49	42	59	44
50	40	35	49	37
15	35	30	43	29

Fig. 7: Illustrate the effect spectral wave numbers on the roundness variations.
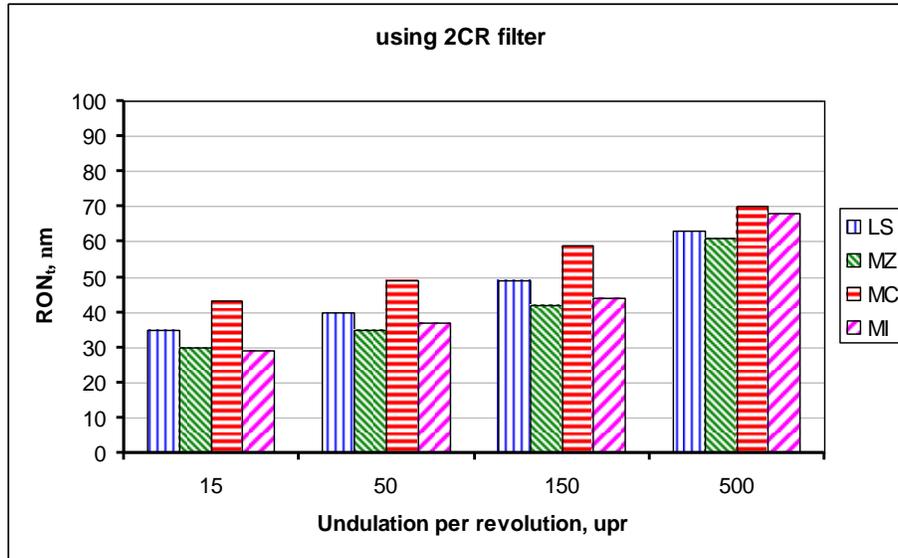
Fig. 8: The RON_t using four algorithm techniques at different spectral wave numbers

5. ANALYSIS AND ESTIMATION OF ROUNDNESS ACCURACY

The computational geometric effects of peak, valley and total errors in roundness metrology using LS fitting technique have been analyzed. The relative results of these errors are presented in Tables 7-9. Table 7 indicates the rate of improvement of the peak roundness error signals (RON_P) at using Gaussian- and 2CR- filters and none-filter when fitting algorism is LS technique. While Table 8 indicates the rate of improvement in valley roundness error signals (RON_v). Table 9 presents the achievement rate of RON_t at the certain conditions. Thus, it can say that, if the metrologest select the suitable measurement strategy with Gaussian filter at LS fitting technique, it gives lower computational errors of both RON_P, RON_V and RON_t in measurement especially at 15 upr using Talyrond HPR Machine.

The experiments revealed that the maximum roundness accuracy improvement could be high with 68% achieved at 2CR fitting filter, while the average roundness accuracy improved is found by about 59.6% using Gaussian fitting technique. Moreover, the average roundness accuracy could be high achieved as 63.3% at 2CR filter, while the average roundness accuracy improved is found by about 55.1% using Gaussian fitting technique which proved the effectiveness within application range.

Table 7: Improvement rate of peak roundness accuracy using two filters at LS fitting algorithm

Frequency	Improvement in RON_P measurement		
	None	Using Gaussian, %	Using 2 CR, %
500		59.6	68.1
150	47.0	40.4	48.9
50		34.0	38.3
15		29.8	31.9

Table 8: Improvement rate of valley roundness accuracy using two filters at LS fitting algorithm

Frequency	Improvement in RON_P measurement		
	None	Using Gaussian, %	Using 2 CR, %
500		55.1	63.3
150	49.0	46.9	51.0
50		42.9	44.9
15		38.8	38.8

Table 9: Improvement rate of total roundness accuracy using two filters at LS fitting algorithm

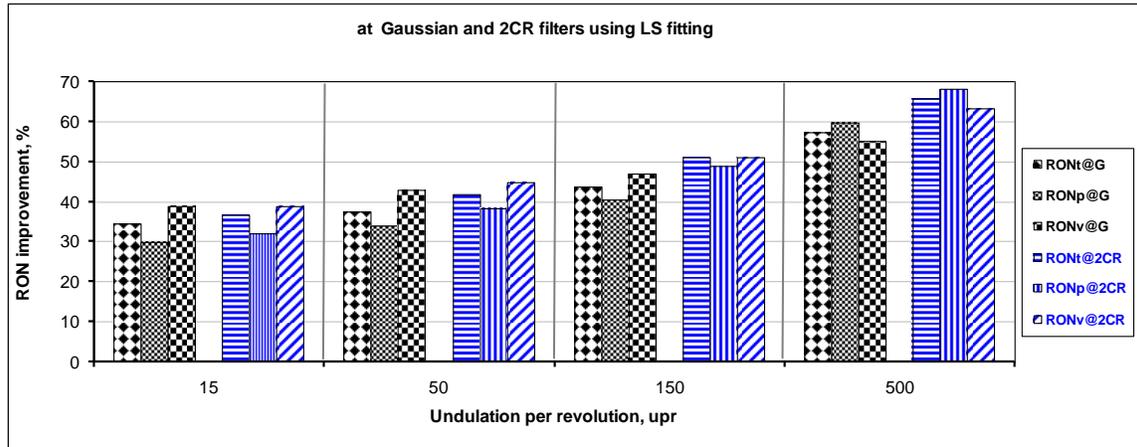| Frequency	Improvement in RON_t measurement		
	None	Using Gaussian, %	Using 2 CR, %
500		57.3	65.6
150	96.0	43.8	51.0
50		37.5	41.7
15		34.4	36.5

Fig. 9: Illustrate the effect spectral wave numbers on the RON_t, RON_P and RON_V accuracy variations

6. CONCLUSION

This work is done through evaluation program for data analysis of software algorithm techniques to a chive development in roundness measurement accuracy. New experimental investigation made for establish computational geometric set to improve the roundness accuracy of Talyrond 73 HPR instrument. The experimental methodology proposed requires ten main parameters have been studied and discussed in details at certain constraints, due to they direct critical impact in form metrology. The results showed that the accuracy of roundness form measurement of object feature is a great challenge front metrologist chiefly in NMIs. Conclusion can be drawn:

1. There are error differences of roundness metrology in the same artifact detecting circle; this due to selection of different fitting algorithms, fitting filters and frequency range in measurement which have difference responses according to their software design within the maximum permissible error.
2. The deviation in the measurement error of roundness is not affected by the number of spectral waves in the absence of any filter.
3. Deviation in roundness measurement increases with increasing the spectral wave numbers in the event of any type of filters may due as a result of the response impact of the filter design.
4. The accuracy improvement in roundness measurement is achieved when using Gaussian filter better than 2CR filter. Of course, both filters give better response than absence of any filter.

5. Improvement in roundness measurement accuracy when use MZ fitting technique is achieved than using MC technique, more than MI technique respectively.
6. There is great variation in the accuracy of measurement for roundness feature up to twice using fitting strategy parameters from 1-15 to 1-500 upr, respectively.
7. Result clearly indicates that the contact stylus Talyrond HPR (TR-73) technique as an ultra high precision machine one from advanced nanometrology machines is powerful tool to get the object feature requirement of roundness measurement for NMIs traceability, professional tests, and modern engineering industries.

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