PRODUCT WHOLE GEOMETRY

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ABSTRACT

The main objective of this paper is to define clearly the concept of "Whole Geometry" and is also directed towards emphasizing the importance of implementing this concept in the evaluation of part geometry. This work also explains how most of the geometrical errors are related to each other and thus introduces new methods for obtaining data and computing techniques. An application software was then designed and developed to account for the above mentioned points to facilitate the process of part evaluation according to the "Whole Geometry" concept. A general case study using the developed software is demonstrated.

Keywords: Whole geometry, Product accuracy, Best-fit, Dependability of geometric errors.

1. INTRODUCTION

The continuous need for greater precision in manufacturing and more reliable products has always emphasized the importance of better understanding of sources of errors. Product errors may be divided into three main groups: dimensional errors, geometrical errors, and degree of surface finish the minimization of which will result in a more accurate product but on the other hand will lead to an increase in product cost. In other words, the product cost is directly related to the amount of error that may be tolerated. The conflicting goals of better products with reduced costs suggest the introduction of better tolerance allocation methods that insure achieving the required product quality at minimum cost. It is also essential to understand that errors arise not only from manufacturing but also during assembly and functioning. The relation between these sources should not be ignored if an accurate evaluation of the functional performance for the product is required. The goal of cost minimization should also be achieved by introducing better inspection technology, which again emphasizes the need for better tolerance allocation and measurement techniques.

2. IMPORTANCE OF PRODUCT WHOLE GEOMETRY

The importance of product whole geometry arises from the need for a faster, more accurate method for the evaluation of part geometry. Traditional methods used to evaluate geometrical errors are time consuming in the sense that they are capable of obtaining the value of only one single geometrical error for each measuring set-up and procedure. Therefore in order to obtain a complete evaluation of the part geometry, a number of measurements must be performed each, sometimes, needing different set ups and different measuring equipment. Much more than this, the same measuring setup may be repeated several times, each time changing the method of data collection, in order to accommodate for the various geometrical errors. The concept of product whole geometry simplifies the process of geometrical error evaluation by almost unifying the measurement procedure for most of the geometrical errors and as a result of this not only a much faster and simpler evaluation is performed by also through a single measuring procedure a number of geometrical errors can be evaluated with improved accuracy.

3. GEOMETRICAL ERROR EVALUATION USING BEST-FIT METHOD

The interpretation of the measured data for the purpose of evaluating geometrical errors, in this work, has been performed using the best-fit concept. In earlier work the interpretation of the measured data has been specified using many different standards. These specifications are all based on the minimum zone concept appearing in ISO/r1101 which specifies the form errors in a general scope. It states that an ideal geometrical feature must be established from the actual measurements such that the maximum deviation between the ideal and the actual measurements concerned is the least possible value. The peak to valley distance of the deviation data from the ideal geometrical feature thus established is taken to represent the form error. The orientation of the ideal feature can be regarded as the alignment error in setting the reference axis with respect to the measured axis.

A strong point that has to be discussed is the need for a calculation method that gives the closest value to the actual value of error of the feature being evaluated, which is not always the smallest value. When performing a certain measurement the value of the obtained geometrical error is a function of several parameters. Taking straightness error as an example, among these parameters are the length being tested and the number of points being measured. If for the same part the measurement and evaluation was repeated several times using the minimum zone method, each time changing the number of measured points, the obtained straightness error shall differ accordingly, whereas it should have been constant. Using the best-fit method, the best fitting line shall give a representation of the trend of the line being measured and in this case the change in number of measured points has a less significant effect on the calculated error, thus the error calculated using the best-fit method is more accurate. As the number of sampled points is increased, the difference between the calculated errors using both methods is reduced as they both approach the actual value of error.

To prove the above argument several shapes of straightness errors were studied. An example of these various shapes is shown in Figure (1). For each shape, the straightness error was calculated using the best-fit and minimum zone methods then the number of sampled points was changed and the error was recalculated using both methods. Table (1) summarizes the calculated errors using both methods for the various cases. The results show that the best-fit method always gives a value of error that is more accurate, if not the same as, than the minimum zone method.

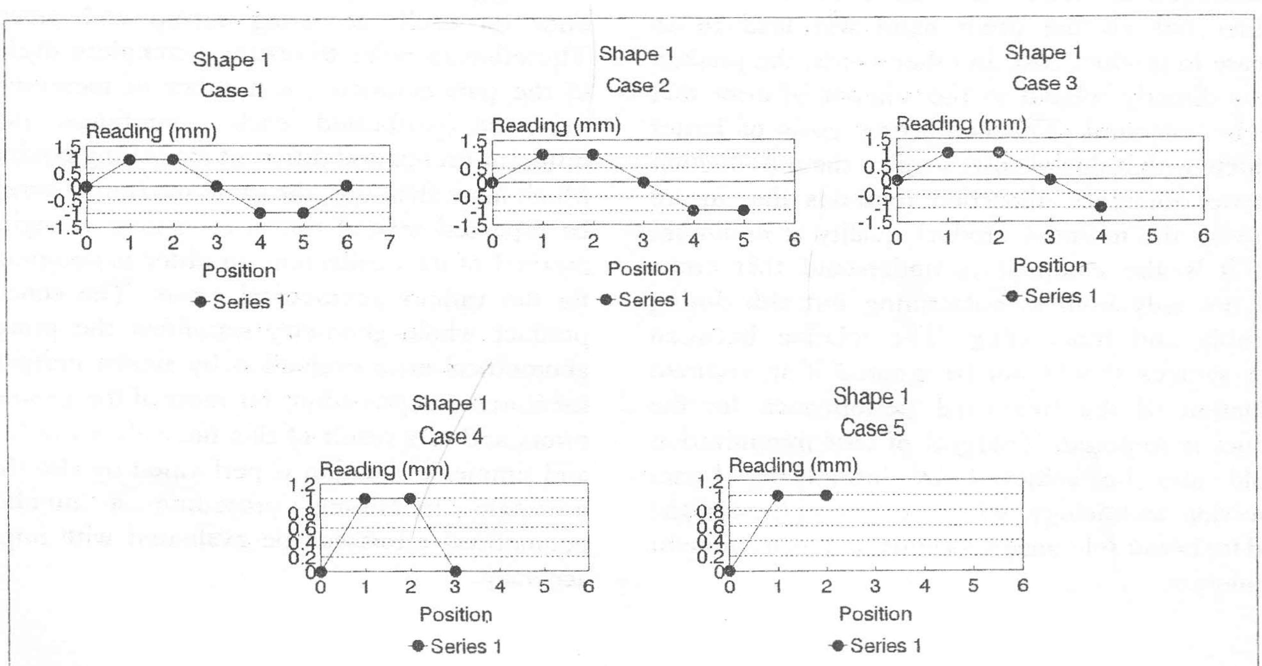

Figure 1. Example of straightness error shapes with various cases for number of sampled points.

Table 1. Calculated straightness errors using minimum-zone and best-fit methods.

CASE	MINIMUM ZONE METHOD TRUE VALUE (mm)	MINIMUM ZONE METHOD CALC. VALUE (mm)	MINIMUM ZONE METHOD PERC. ERROR (%)	BEST FIT METHOD TRUE VALUE (mm)	BEST FIT METHOD CALC. VALUE (mm)	BEST FIT METHOD PERC. ERROR (%)
1	2.0000	1.4389	28.1	2.0000	1.5714	21.4
2	2.0000	1.4391	28.0	2.0000	1.6857	15.7
3	2.0000	1.4391	28.0	2.0000	1.6000	20.0
4	2.0000	1.0000	50.0	2.0000	1.0000	50.0
5	2.0000	0.4206	79.0	2.0000	0.5000	75.0

To further prove the improved accuracy of the best-fit method over the minimum zone method, an orifice with nominal shape shown in Figure (2) was evaluated. Two types of errors were superimposed on the nominal shape of the orifice. The individual effect of each of these errors and the combined effect on the orifice's nominal shape are also shown in the same figure. The evaluation of these errors, treated individually and combined, was performed using both calculation methods. Table (2) summarizes the errors calculated using both methods. The results again prove the best-fit method to be the more accurate calculation method.

4. RELATION BETWEEN GEOMETRICAL ERRORS

4.1 *Geometrical error relation network*

The concept of "whole geometry" states that there is a clear relation between the various geometrical errors, this relation is shown in the network shown in Figure (3). This idea arises from the understanding of the different measurement techniques for the various geometrical errors. When these techniques are studied thoroughly, it is clear that most of them are similar but only differ in the method and order of data collection. Also examining the different geometrical errors shows that most of these errors are related to the straightness error.

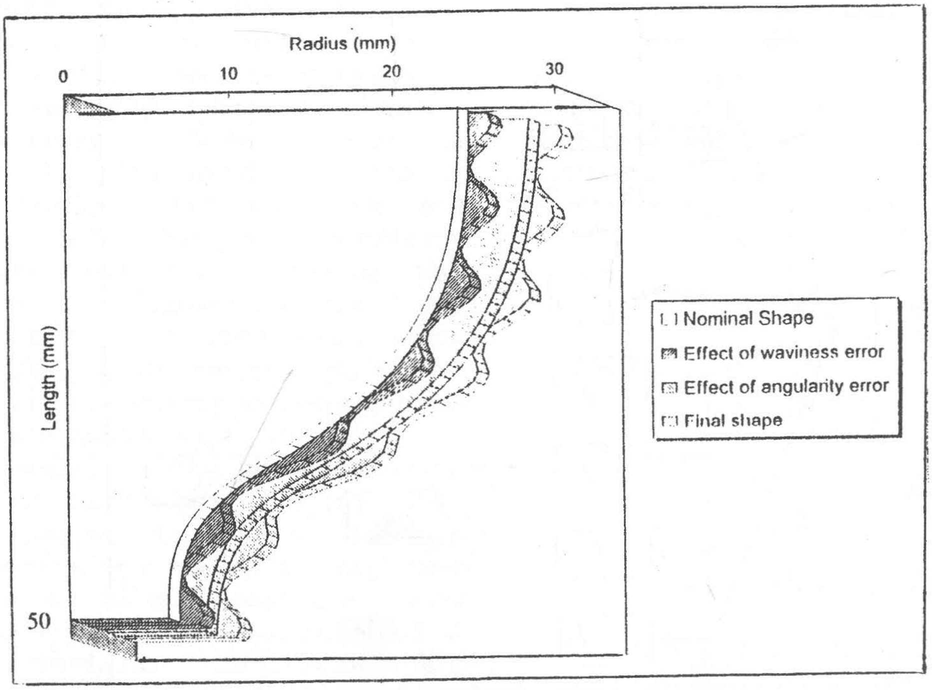

Figure 2. Effect of conicity and waviness errors on orifice shape.

Table 2. Calculated conicity and waviness errors using minimum-zone and best-fit methods.

A) EFFECT OF ANGULARITY ERROR

Evaluation Technique	ACTUAL ERROR (DEG.)	CALCULATED ERROR (DEG.)	PERCENTAGE ERROR(%)
MINIMUM ZONE METHOD	0.50000	0.47457	5.09
BEST FIT METHOD	0.50000	0.49950	0.10

B) EFFECT OF WAVINESS

Evaluation Technique	ACTUAL ERROR (mm)	CALCULATED ERROR (mm)	PERCENTAGE ERROR (%)
MINIMUM ZONE METHOD	0.40000	0.40002	0.005
BEST FIT METHOD	0.40000	0.40015	0.038

C) EFFECT OF ANGULARITY AND WAVINESS ERRORS

Evaluation Technique	Angularity Error			Waviness Error		
	ACTUAL ERROR (mm)	CALCULATED ERROR (mm)	PERC. ERROR %	ACTUAL ERROR (mm)	CALCULATED ERROR (mm)	PERC. ERROR %
MIN. ZONE	0.50000	0.47778	4.440	0.40000	0.38324	4.19
BEST FIT	0.50000	0.50294	0.0059	0.40000	0.40258	0.60

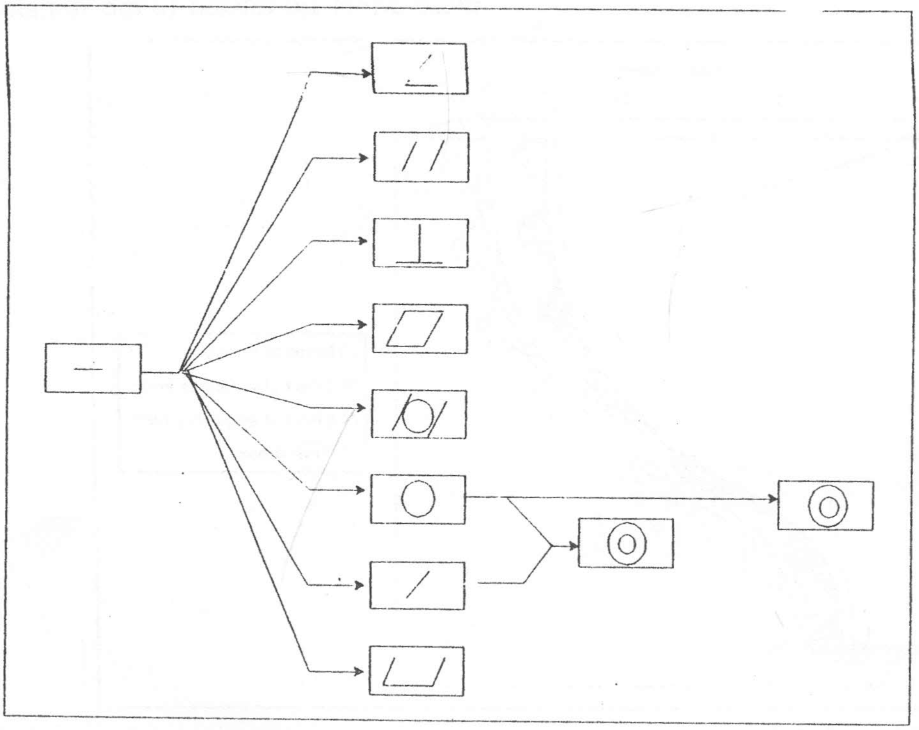

Fig. 3 Geometrical error relation network.

4.2 *Method of obtaining data*

As it was stated earlier, the main objective of implementing the "Whole Geometry" concept is to obtain a complete evaluation of the part geometry through performing a number of measurements that is greatly reduced when compared to traditional measurement techniques. To achieve this objective the method of measurement for most geometrical errors was simplified in the sense of making it possible to evaluate those errors through performing a number of straightness error tests.

Implementing the concept of "Whole Geometry" also simplified the method of measurement by making it more versatile in the sense of making fewer set-ups eligible to accommodate for the evaluation of most of the geometrical errors. This resulted in making the process of evaluation of a number of geometrical errors in a part, in order to give a complete description of the part geometry, not constraint on three-dimensional measuring equipment but also applicable to the less sophisticated two-dimensional measuring equipment already available in many metrological laboratories. Much more than this, equipment were simpler and more flexible to adapt for the various part shapes.

It is well known, for example, that the measurement and evaluation of cylindricity error is a tedious and time consuming procedure. Therefore, it is common practice that every consideration should be given to the use of other geometrical tolerancing methods before specifying cylindricity tolerance. Suggested tolerancing methods, in order of preference, are 1) Total runout, 2) Separate tolerancing of circular runout, straightness, and parallelism, 3) Separate tolerancing of circularity, straightness, and parallelism. Knowing that cylindricity error is an important feature to be evaluated and that is, in most cases, being disregarded because of its complications it was important to look for new techniques to evaluate this error in a much less tedious way.

Now having a closer look at the network shown in Figure (3), the network indicates that it is possible, for example, to compute the value of cylindricity error through performing a number of straightness error measurements. To understand how this is possible it is necessary to review the definition of cylindricity error which states that cylindricity is a condition of a surface in which all points of the surface are at the same distance from a common axis. The cylindricity tolerance is a composite control of form that includes circularity, straightness, and parallelism of the surface elements of a cylindrical feature. It is like a flatness tolerance wrapped around a cylinder. Studying the above mentioned definition shows that a cylindrical profile may be very well defined by means of a number of generators each being nominally a straight line, in contrast to defining the cylinder as being a number of circles each having its center along the same straight line. The method by which a geometrical feature is defined influences the method by which it shall be measured, this is why it has been common practice to evaluate the value of cylindricity error through a number of circularity measurements or through the measurement of a spiral profile. For the purpose of making the process of geometrical error evaluation simpler to perform, as stated earlier, we should try to make the process of measurement as simple as possible and this is achieved, as for the case of cylindricity error, by relating most of the geometrical errors to the straightness error and by using the appropriate algorithm the required error can be calculated. In order to show the improved accuracy of implementing the proposed method of measurement and evaluation over traditional methods the value of flatness error of a part surface was calculated using three-dimensional measurements using equation {1} which gives the distance between the two furthest points from the best-fitting plane represented by equation {3}.. Equation {2} gives the distance between the best-fitting plane and the measured points on the part surface. The constants equation {3} are found by substituting the values of the measured surface in equations {4}, {5}, and {6}.

$$Flatness\ error = d_{max} - dmin \tag{1}$$

$$d = \frac{DX - Y + CZ + A}{\sqrt{B^2 + (-1) + C^2}} \tag{2}$$

$$Y = A + BX + CZ \tag{3}$$

$$\Sigma Y = NA + B\,\Sigma X + C\,\Sigma Z \tag{4}$$

$$\Sigma XY = A\,\Sigma X + B\,\Sigma X^2 + C\Sigma XZ \tag{5}$$

$$\Sigma ZY = A\,\Sigma Z + B\,\Sigma XZ + C\Sigma Z^2 \tag{6}$$

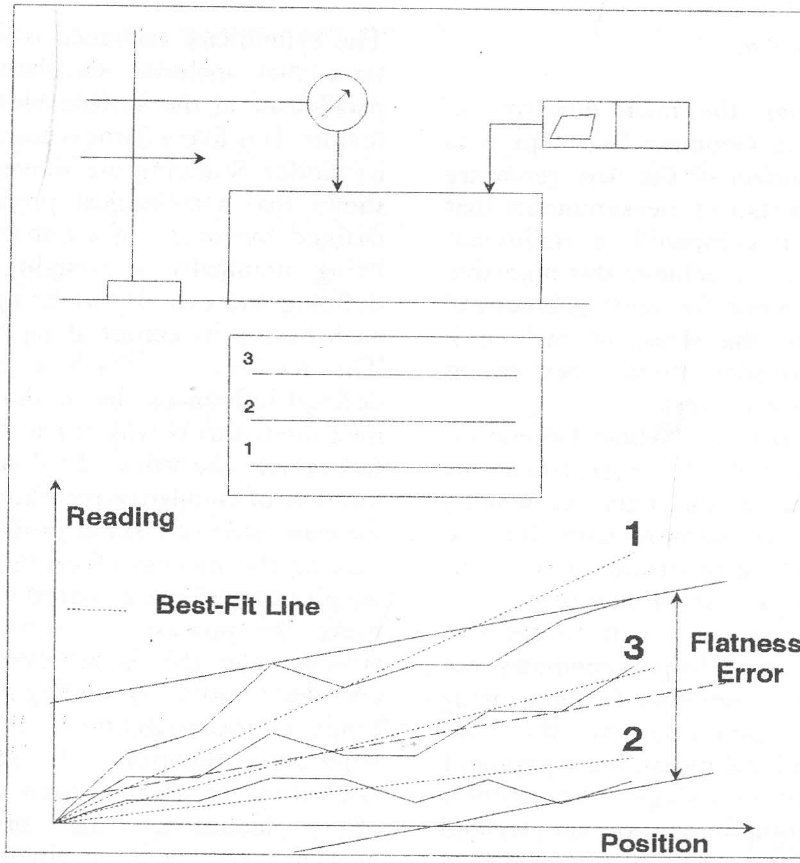

Figure 4. Method of measurement and evaluation of flatness error using multiple straightness error measurements.

Table 3. Calculated flatness error using three-dimensional evaluation and multiple straightness measurement technique.

EVALUATION TECHNIQUE	FLATNESS ERROR (mm)
THREE DIMENSIONAL EVALUATION	0.152
PROPOSED TECHNIQUE	0.139

The flatness error of the part surface was also evaluated using the proposed technique, Figure (4) shows the method of measurement and evaluation using the proposed technique. Table (3) lists the value of the flatness error calculated using both methods. The proposed method gives a smaller value of error and thus this method is more conforming to the ISO/r1101 standard.

5. DESIGN AND DEVELOPMENT OF WHOLE GEOMETRY APPLICATION SOFTWARE

In order to make the concept of "Whole Geometry" easier to implement, it was necessary to design a computer software that includes most of the product shapes encountered in industry and that accommodated with the most frequently encountered geometrical errors to be evaluated.

The designed program was constructed using the Micro-Soft Visual Basic software version 3.0 for windows. The program was designed as a friendly user software to instruct the operator throughout the entire procedure of geometrical error evaluation. The program was designed to perform all geometrical error calculations using the best-fit concept discussed earlier.

A flow diagram of the software sequence is shown in Figure (5). The program starts by introducing a welcoming screen introducing "Whole Geometry". Upon clicking on the appropriate button in the main menu, a number of product shapes will be displayed for operator selection. Figure (6) shows a hard copy of the main menu. Different screens for error selection, sample of errors included in the final report, and measuring procedures and set-ups supported by on-line help, which makes it easy to use even for the inexperienced operator with minimum knowledge, screens shall then be introduced to guide the operator through the entire process of the part shape evaluation. Finally result screens shall be displayed giving a complete evaluation of the part's geometrical errors.

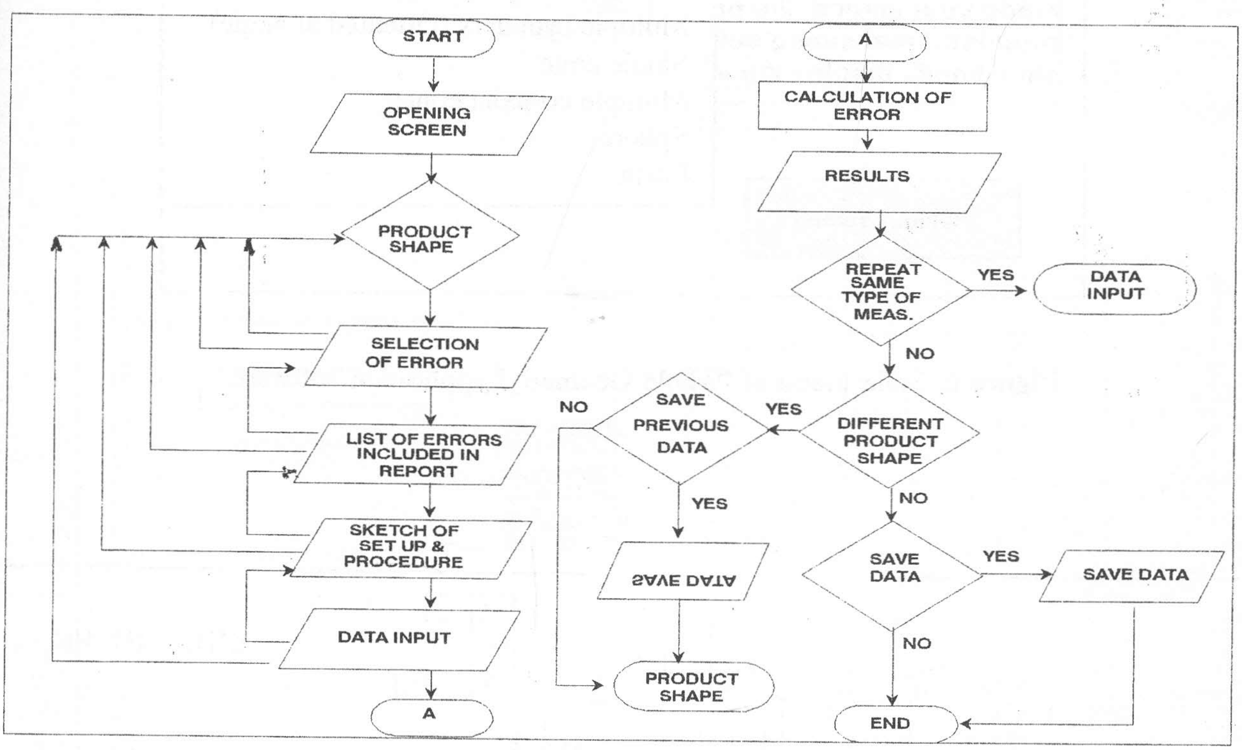

Figure 5. Flow diagram of "Whole Geometry" application software.

6. GEOMETRICAL ERROR EVALUATION OF A DRIVING SPINDLE.

A driving spindle of a soft sealing gate valve manufactured by El-Nasr Castings Co., Alexandria, Egypt was chosen among a number of manufactured parts to be evaluated using the developed "Whole Geometry" application software. Figure (7) shows a part drawing of the selected driving spindle in which some geometrical errors are chosen for evaluation.

The appropriate product shape was selected from the main menu and data were entered. The measurements were carried out on a large tool maker's microscope. The selection of the measuring equipment was based on the proposed measuring set-up introduced by the software and availability. Figure (8) shows some of the software screens demonstrating the software procedure, data entry screens, and results.

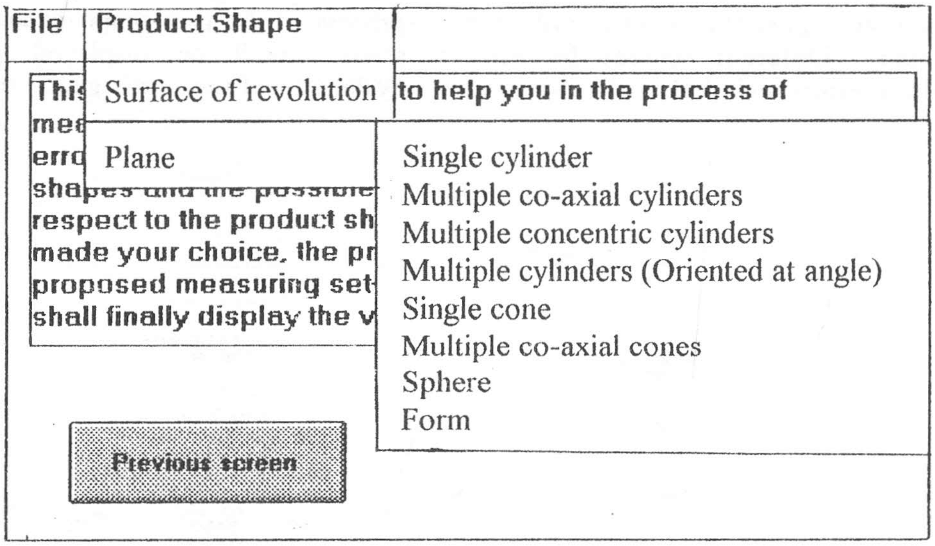

Figure 6. Main menu of "Whole Geometry" application software.

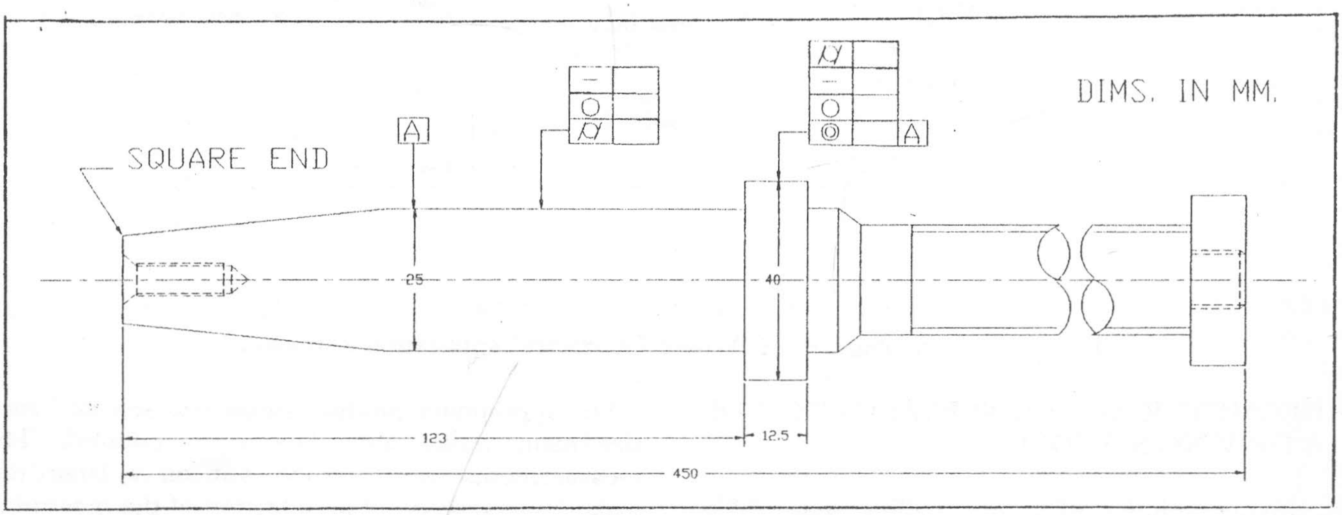

Figure 7. Part drawing of measured driving spindle.

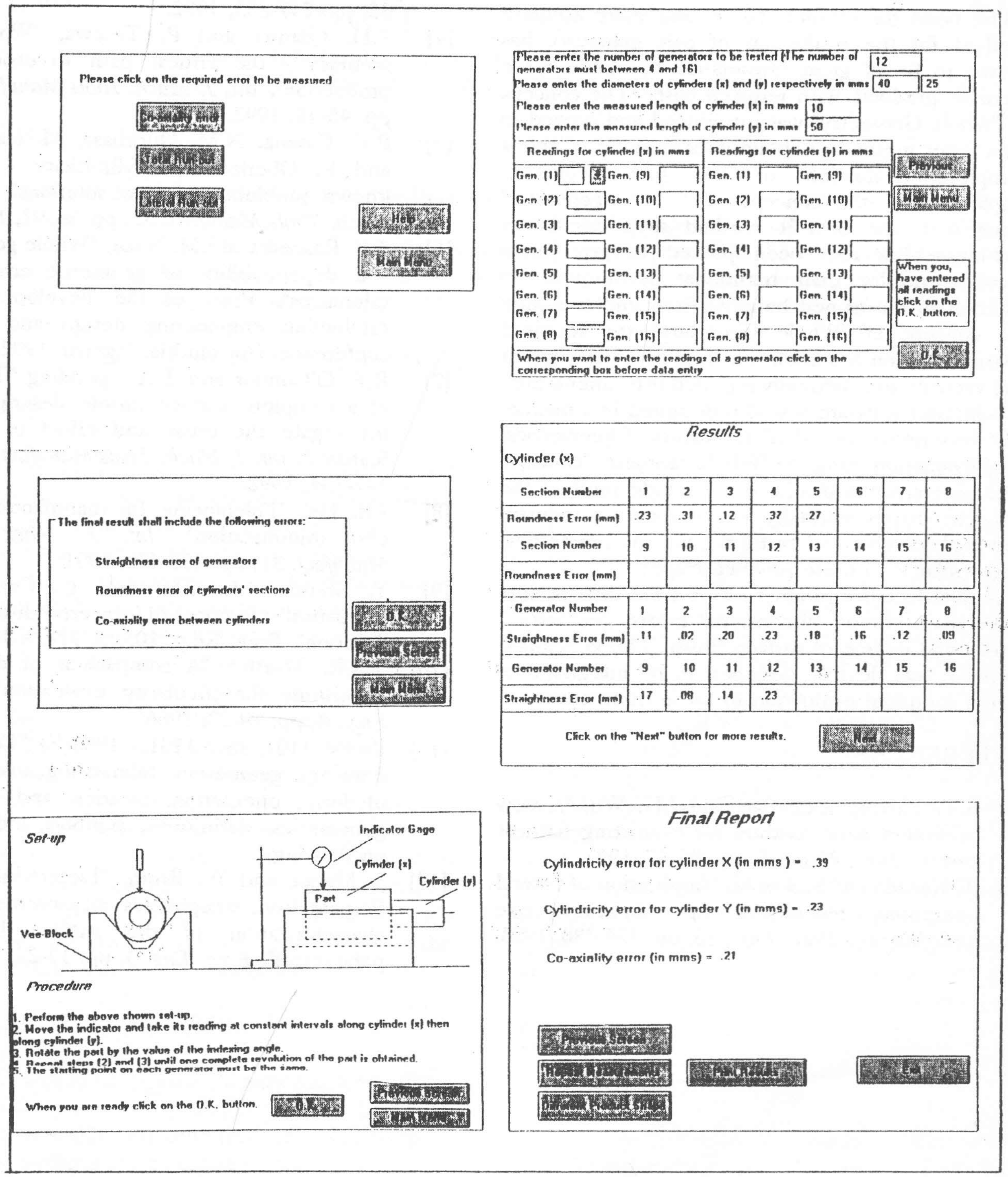

Fig. 8 Selected sample screens of the "Whole Geometry" application software.

7. CONCLUSION

The need for simpler, faster, and more accurate method for the evaluation of part geometry has shown to be of great importance to obtain more accurate products with reduced costs. The concept of "Whole Geometry" was introduced and proved to be a faster method to obtain data required to give a complete evaluation of the part geometry. Implementing the concept of "Whole geometry" along with the best-fit method as a calculation technique has also been proved to give more accurate results than traditional techniques. In addition to the gained benefits from implementing the concept of "Whole Geometry" the required instrumentation has been shown to be much simpler and versatile than normally required instrumentation. A computer software was also designed in a manner that very much simplified to process of geometrical error evaluation using the "Whole geometry "concept. The program was designed to include most of the program shapes normally encountered in industry and to also accommodate for the various geometrical errors related to these product shapes.

As stated earlier product errors were divided into three main groups: dimensional errors, geometrical errors, and degree of surface finish. The developed software was flexibly designed to be integrated to give a complete evaluation of these three errors.

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