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COMPUATION METHOD FOR TESTING OF WORK PIECES USING COMPLETE GAUGING

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Abstact: The paper describes a new precision evaluation method for testing of the work pieces under enveloping conditions using complete gauging, as defined by ISO 1101 and ISO 2692. The method permits a reliable examination of the best fit elements in a very complex geometry under consideration of all defined links between the geometric elements and all defined tolerance zones, with the least fault zones.

Keywords: *co-ordinate metrology, complete gauging of work piece, tolerance-fit, interlinked geometric elements*

1. INTRODUCTION

The present paper relates to an evaluation method with the least fault zones for on-line geometric computation of several interlinked geometric elements with defined tolerance zones as per [1] and [2].

Testing a work piece under enveloping conditions requires a complete gauging as per Taylor principle. Our idea to fulfil this requirement was born 1994 [3]. Since 1995 we have developed the algorithms and software program, which simulate this test by making a complete evaluation over complex tolerance ranges, and yields not only substitute parameters as per Chebyshev but also the gauged parameters of every geometric element [6, 7].

The interlinking conditions in the respective tolerance range are thereby fully met, while a minimum deviation of size, position and form are ensured. The shape of each interlinked geometric element is the best-possible one!

2. BEST-FIT EVALUATION OF WORK PIECES WITH DEFINED TOLERANCE ZONES

Our investigations have shown that the direction vector of most Chebyshevian elements can be inclined by a small angle and/or shifted by a small measure without changing its best form in any practicle term. The method which makes such a research possible is described in a separate paper at this Congress (Reg. no. 607: "New Evaluation Method for Testing of Simple Geometry and Work Pieces").

Using new fundamental objective and the effect described here (in many practical cases) the shape of each gauging element of a work-piece hardly differs from the corresponding entire Chebyshev best-fit element.

The existing evaluation methods in CMM apply only to single geometric elements The simple linking together of the partially evaluated parts of work-pieces can consequently lead to the statement that the results of the geometric quality control of the work-pieces are worse than the manufacturing itself; that is to say that the work-pieces whose measures are between the tolerance limits by the customary evaluation might wrongly be declared as rejects and that the manufacturing tolerances of the follow-up work-pieces are unnecessarily kept too narrow. These perceptions and the importance of the presented method for the economic manufacturing in automotive and machine building industry was published 1995 in [6, 7].

Every required connection condition, which has been given in input of the work piece evaluation**,** is practically acting as a restriction which inclines and/or shifts the axis of the best Chebyshev surface in the required direction. On the other hand the given tolerance relieves the restriction area by the value of the tolerance range. Since all surfaces are to be evaluated simultaneously, the surfaces will adopt such axis directions, position and size of elements, that the required relationships of the work-piece will be fulfilled by the best feasible forms of all surfaces for the prescribed conditions. If some of the surfaces are more or less important than others, the iterative gradients of these surfaces are to be increased or decreased accordingly (multiplied by a weighing).

3. ALGORITHM FOR COMPLETE GAUGING

The fundamental method follows a clearly defined objective:

To find the least fault zone of every geometric element in a complex work piece under consideration of all defined and tolerated links between the geometric elements.

The common fundamental objective for a work piece is constructed as a polynomial. Initially, the method starts with the method for finding the starting parameters of single geometric elements by data fitting according to the least squares method setting the deviations = 0 [4, 5].

The least squares objective for start parameter of a cylinder reads as follows:

$$\mathbf{F} \equiv \sum_{0}^{n}\Big[\sqrt{\Big(} \; [\,(x_i - x_0).ny + (y_i - y_0).nx]^2 + [\,(y_i - y_0).nz + (z_i - z_0).ny\,]^2 + [(z_i - z_0).nx + (x_i - x_0).nz\,]^2\Big) - R\,\Big]^2 = 0 \qquad (1)$$

where: $\mathbf{x_0}$, $\mathbf{y_0}$, $\mathbf{z_0}$ are the position co-ordinates of the cylinder axis; **R** is a radius,

nx, ny, nz are axis direction cosines; ***n*** is number of the points; x_i, y_i, z_i are the co-ordinates of the measuring points.

The linearisation of (1) in a polynomial:

$$\mathbf{F} \equiv \sum_{0}^{n} \Big(x_i^2 + y_i^2 . a_1 + z_i^2 . a_2 + x_i . a_3 + y_i . a_4 + z_i . a_5 + x_i . y_i . a_6 + y_i . z_i . a_7 + x_i . z_i . a_8 + a_9 \Big) = 0, \qquad (2)$$

were $[a_i] = \underline{x} = f_i\,(x_0, y_0, z_0, nx, ny, nz, R)$ (defined by the substitutions, not shown here).

The equation (2) to be developed by the derivations with respect to nine variables $\mathbf{a_i}$ in a known system of the linear equations.

Iterative solution of this system using of the Newton method reads as follows:

$$(\underline{x}_i)^{[k+1]} = (\underline{x}_i)^{[k]} - \underline{J}^{-1} . \vec{g} \qquad (3)$$

where $\underline{x}_i$ are six variables (x_0, y_0, **R, nx, ny, nz**), $\vec{g}$ is a gradient developed by the differentiation of (1) with respect to the variables $\underline{x}_i$; $\underline{J}$ is a Jacobiane matrix developed by the differentiation of the gradient $\vec{g}$ with respect to six variables $\underline{x}_i$; **k** is a preceding improvement step in the iteration.

The further procedure is the same as explained in (6), (7), (8).

The (optional) second step is to find the final least-squares parameters. The well-known objective function for the squares of the point distances f_i reads as follows:

$$\mathbf{F} \equiv \sum_{i=1}^{np} fi^2 \Rightarrow \text{Min.} \qquad (4)$$

The objective (4) to be developed in a well-known non linear equations system. Iterative solution of this system using of the Newton method (see (6), (7) and (8)).

The third step is to find the final parameters using one of the best-fit evaluation methods according to Chebyshev (for instance so called Monte-Carlo method, Simplex-method, Lp approximation) [8, 9,10].

The next step is an selection and arrangement of the geometric elements according to the respective links, reading of all measuring points as well as reading the linkage and tolerance data according to drawing.

The final step is integral evaluation of the gauging elements. The basis for this evaluation is the fundamental integral (common) objective according (5).

The objective is to minimize the polynomial of the maximal deviations for **m** surface objectives by Chebyshev, including all necessary mathematical conditions as well as all prescribed connecting conditions (relationships) between the surfaces with its tolerances in accordance with the drawing:

$$\mathbf{F} \equiv \sum_{0}^{m} \Big\{ g_1 |\nabla|_1 + g_2 |\nabla|_2 + \dots + g_m |\nabla|_m \Big\} + \lambda_v\,(\underline{\mathbf{mat}}_v) + \lambda_k\,(g_k . \underline{\mathbf{Con}}_k + \varphi_D + \mathbf{tol}_k . \sin(\alpha_k)) \Rightarrow \text{Min.}, \qquad (5)$$

where $|\nabla|_i = \left|\nabla\right|_0^{np}{}_i$ = an objective (minimize the maximal deviations for each of **m** surfaces); ***m*** is the number of the surfaces; ***np*** is number of the associated measured points for each element; **k** is number of the prescribed and tolerated connections; **v** is number of the necessary mathematical connections; g_m are weighing factors of the individual surfaces according to their importance; g_k are weighing factors of the individual conditions according to their importance; λ_v, λ_k Lagrange multipliers, the expression ($\underline{\mathbf{mat}}_v$) are mathematically necessary conditions like ($nx^2 + ny^2 + nz^2 - 1 = 0$); **nx, ny, nz** are axis direction cosine; the expressions ($\underline{\mathbf{Con}}_k + \varphi_D + \mathbf{tol}_k . \sin(\alpha_k)$) are prescribed connecting conditions of interrelated surfaces in accordance with the drawing; $\underline{\mathbf{Con}}_k$ are angle conditions (such as parallelism, orthogonality, inclination) or distance conditions between the interrelated surfaces in accordance with the drawing; φ_D is the average difference range of size or angle. If a prescribed tolerated range is not symmetrical, than it will be set at average tolerance range and the eccentricity (positive or negative difference between the 0-value and the average value) will be added to the respectively prescribed size or angle condition; $\mathbf{tol}_k$ are tolerance ranges (boundaries) of the connections of interrelated surfaces in accordance with the drawing (see Fig. 1); α_k are auxiliary parameters ($0 < \alpha_k <$ 2 which also be improved by iteration; $\sin(\alpha_k)$ sine or cosine function ensuring, that the prescribed tolerated range can not be exceeded.

The objective (5) to be developed in a well-known non linear equations system. An iterative solution of this system using of the Newton method is:

$$(\underline{a}_i)^{[k+1]} = (\underline{a}_i)^{[k]} - \underline{J}^{-1} . \vec{g} \qquad (6)$$

where $\underline{a}_i$ are parameters of each element,

$\vec{g}$ is a gradient developed by the derivations of (4) with respect to the parameters $\underline{a}_i$,

$\underline{J}$ is a Jacobiane matrix developed by the particular derivation of the gradient $\vec{g}$ with respect to the parameters $\underline{a}_i$; **k** is a preceding improvement in the iteration.

$$\text{because: } \underline{J} . \vec{\Delta} = \vec{g}, \qquad (7)$$

the equation (2) can be transformed into a more practical expression:

$$(\underline{a}_i)^{[k+1]} = \vec{\Delta} + (\underline{a}_i)^{[k]}, \qquad (8)$$

where $\vec{\Delta}$ are the iterative improvements of the searching parameters.

By this method it is ensured, that all the changes of the best Chebyshev forms for all elements, which are previously separately evaluated, are the least, while the required tolerated connections are fulfilled. The shape of each interlinked geometric element and complete gauging of the work piece is the best- achievable one!

The integral evaluation method is virtually proved in the program-package *CMM-Integral A&B Logical Software* and practically proven in automotive and machine building industry and has passed all national and international software tests. This software program can master hitherto inconceivable tasks, e.g. the evaluation of integrally tolerated, crankcases, connecting rods, cylinder blocks, and complicated cast or plastic work pieces, etc.

With the help of this program all tolerances given in the input can be quickly reduced on a lower level, for instance on 50% or 60% of the tolerance fields given in the drawing.

On this way a clear statement is possible whether the work piece is acceptable and in addition a quality tendency can be given (warning limit).

The parameters obtained with the aid of our software are without reservation the best. This allows to achieve the best minimum or maximum material conditions.

The algorithm for complete gauging is shown in Fig. 1

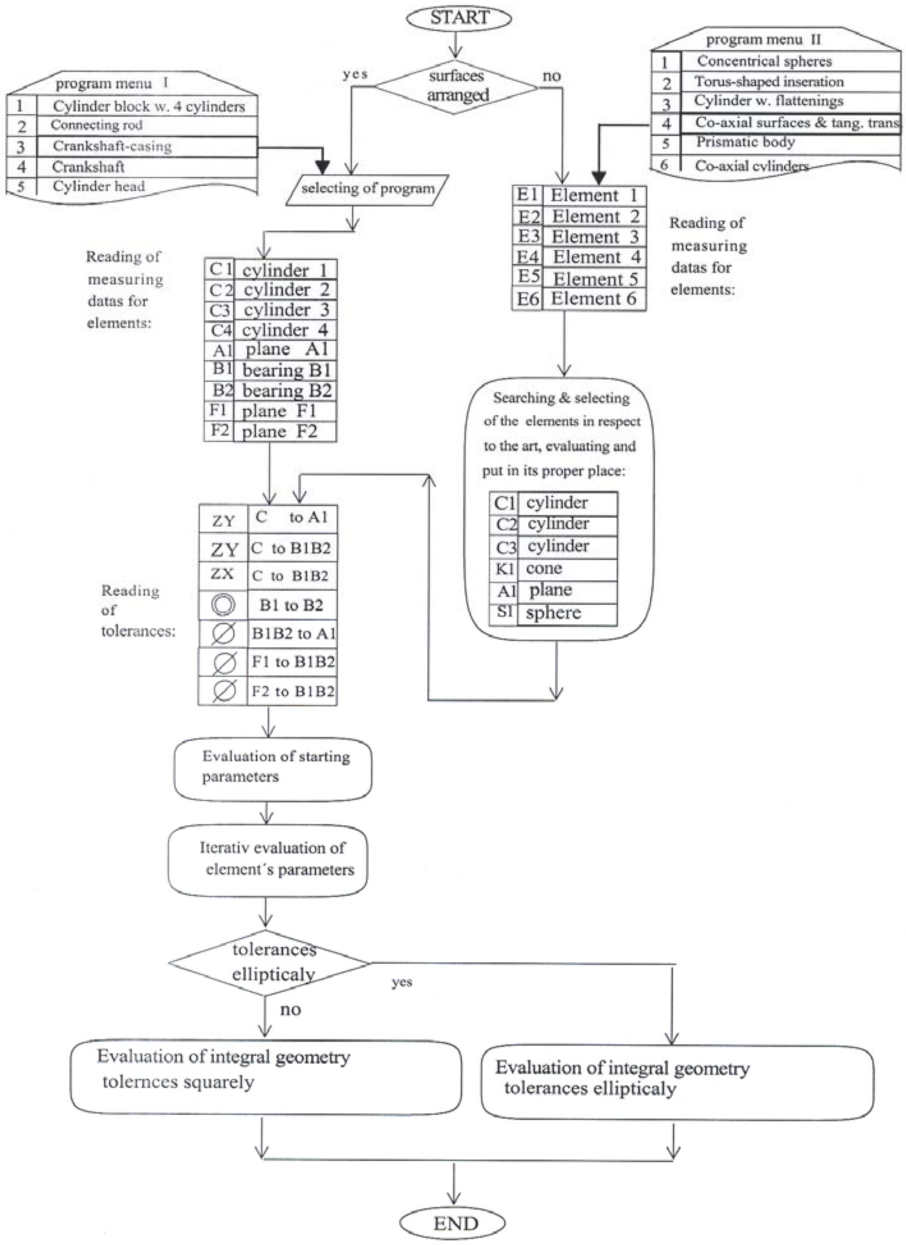

Fig. 1: Flow chart for complete gauging of a work piece

Input:

(a) CMM - measuring points
(b) relationships between form-generating surfaces as defined in the drawing
(c) feeler data
(d) defined tolerances in all projections according to drawing (or tolerances reduced e.g. on 60%)
(e) kind of tolerated boundary (square or elliptical)

Output:

(i) Chebyshev evaluation of each surface
(ii) integral evaluation of all surfaces within their relationships and tolerances as per drawing with the best achievable shape of each geometric element.

- stable and repeatable evaluation with Chebyshev algorithm and as unequivocal as the least-square principle
- real evaluation in 3-dimensional space without any transformation
- insensitive to wide scattering of measuring points
- no preparation necessary for fixing the work piece in any desired way in the 3-D space
- absolutely ideal for scanning measurements
- possibility of applying wider tolerances in the drawings without detriment to quality
- range from minimum number to several thousand measuring points
- up to several dozen elements and links with tolerances
- tolerance links in all planes of projection in any shape (round, quadratic, elliptical, etc.)

Independent of the method of surface scanning (a "cloud of points" is also perfectly adequate), all standard geometric elements are automatically, i.e. "blindly", detected and evaluated.

The program-package is easy to operate. One does not need to be a computer expert to use the *CMM-INTEGRAL*.

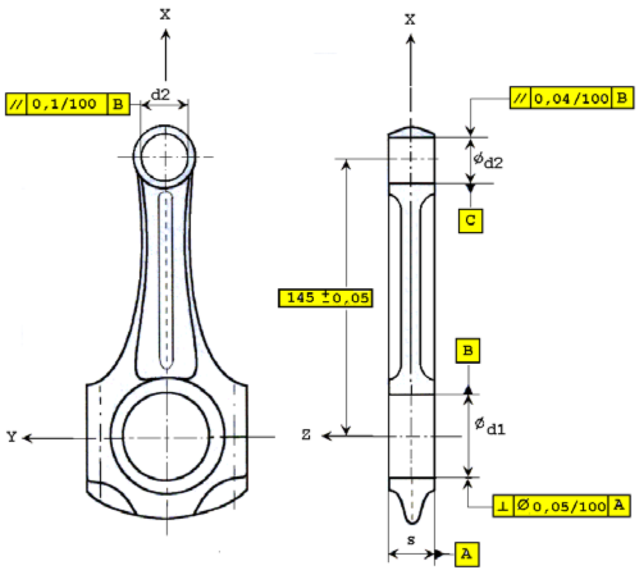

Fig. 2. Example of interrelated surfaces by a connecting rod

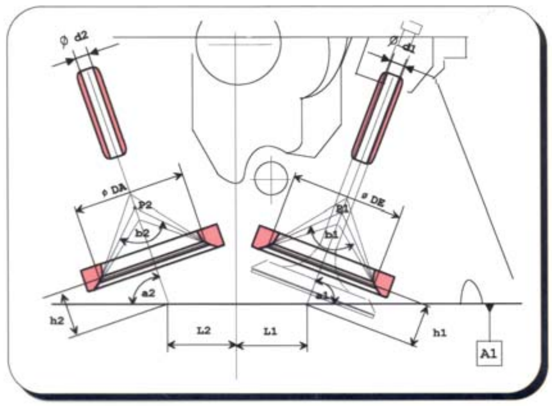

Fig. 3. Cylinder head evaluated integral

4. SUMMARY

The presented algorithm ensures the precision testing of the work pieces under enveloping conditions using complete gauging, as defined by ISO 1101 and ISO 2692.

The testing of a work piece under enveloping conditions requires a complete gauging as per Taylor principle. The described method simulates this test by making a complete evaluation over complex geometry, under consideration of all defined links between the geometric elements and all defined tolerance zones, with the least fault zones.

Every required connection condition, which has been given in input of the work piece evaluation**,** is acting as a restriction which inclines and/or shifts the axis of the best surface in the required direction. On the other hand the given tolerance relieves the restriction area by the value of the tolerance range. Since all surfaces are being evaluated simultaneously, these will adopt such axis directions, position and size of elements, so that the required relationships of the work-piece will be fulfilled by the best feasible forms of all surfaces for prescribed conditions. If some surfaces are more or less important than others, the iterative gradients of these surfaces shall be accordingly increased or decreased (multiplied by a weighing).

The method is applied in the program-package *CMM-Integral* and successfully proven in automotive and machine building industry for testing of crankcases, connecting rods, cylinder blocks, complicated cast or plastic work pieces, etc.

REFFERENCES

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