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ESTIMATION OF THE STATE OF A PRODUCT PROPERTY BASED ON SIMILARITY OF ITS PARAMETERS

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Abstract

The value i.e. state / level of a quality of a product is done by states of its properties. These are defined during engineering design process. Thus their establishing and determining usually using methods Design for X (DFX) within this starting phase is needed. However many states of properties can be determined exactly with great difficulties (e.g. manufacturing cost, reliability, etc.). In the article the knowledge-based method of estimation prediction of the state of a property of the designed product will be presented. The method is based on the set of known properties of similar products. The method has been verified with use of EXCEL SW and tested on typical examples from industrial practice.

1 Introduction

Any technical product / technical system (TS) is required to fulfil many properties. We will understand as a *property* [5] here any *attribute* of the TS, which describes / characterises it. Consequently besides TS general characteristics and shapes, dimensions, materials, etc. also its operational / transformation functions and their properties, and also TS safety, health protection, appearance, manufacturing, distribution, operational, maintenance and liquidation cost, suitability for manufacturing and transport, environmental compatibility, and many others as TS properties are understood. When speaking about fulfilling of any of these TS properties it is understood achieving its (supposed, estimated, realised) requested (minimal or maximal) level. This level can be expressed either numerically (in measurable units called generally as *parameters*) or (mostly) only linguistically (low, high, good, satisfactory etc. which are sometimes also called as parameters). We call these levels of any property as a *state of a property* (and as parameters measurable states only). Note that some authors call both its qualitative (name of a property) and quantitative (state of a property) contents as a TS property, which can be confusing.

As mentioned above states of TS properties are defined (directly/primarily or indirectly/secondarily or maybe multiply) during engineering design process. However there are TS properties, which are defined directly by engineering designers (e.g. shapes, dimensions, etc.) and others which are caused by previous ones (e.g. strengths, stiffness, etc.), and next ones caused by both previous ones (e.g. functions and their properties, suitability for manufacturing, transport, etc., appearance, safety, delivery time, manufacturing cost, etc.). Consequently during engineering designing there is a need at first to establish (to engineering design step by step) states of the first group of ‘primary’ properties so, to optimally fulfil requests on all considered properties. Use of methods Design For X (DFX) for synthesises is usual within this first phase.

The scope of considered properties [3] often depends on hitherto acquired knowledge and experience, which has been gained by education and practice, and is significantly affected by previously made and corrected mistakes. The next, better possibility is use of methodically and / or empirically prescribed approaches, which recommend among others more or less systematically the scope of properties to be considered. However, because the TS properties exist objectively, i.e. independently on minds of engineering designers, customers, researchers, etc., the best potential for 'not to forget anything important' is hidden according to our opinion at scientifically arranged system (map) of engineering design knowledge including those related to the TS properties [6].

Within the following phase it is necessary to determine the achieved states of (secondarily and multiply dependent) properties as soon as possible before they will manifest themselves in reality because any changes to improve or optimise them will be much more expensive or even impossible. Sometimes it is routine work using methods from different sciences (e.g. calculations of overall dimensions, mass, strengths, stiffness etc.). However many, even numerically defined states of properties, can be determined exactly with great difficulties (e.g. manufacturing, maintenance and liquidation cost, reliability, etc.) till now. The knowledge-based method of prediction of the state of those TS properties which can be estimated from the sets of states of known properties of similar products has been developed to help to solve these problems.

2 Expression of similarities among the TS properties

Let us have a set of ***m*** source variants of TS. The number of TS variants ***m*** is constant for a given task but can change for any next task according to the development of situation. Each variant (***j = 1 – m***) is determined by a vector of ***n*** parameters (independent variables – states of primary properties) denominated from x_1 to x_n . The concept can accept that some of these parameters may be originally given in the vague / linguistic form. However the appropriate fuzzy method for their quantification should have to be applied. If there is ***n*** parameters, the ***n***-dimensional space is considered and each variant ***j*** can be represented by the end point ***J*** of the related vector within this space. Each TS variant (vector) ***j*** has assigned a state of a TS property ***f(j)*** dependent on states of primary properties (parameters) $x_i = x_1 - x_n$ of the TS variant / vector ***j*** . Let us consider now, that these states of properties (values) ***f(j)*** of the source TS variants have been found by an unknown or very complicated way which is not easy or is "even impossible" to find and simplified for practical reuse.

Let us have now next TS variant (vector) ***x*** with known values of its states of TS properties (parameters) ***i = 1 – n*** . Its end point ***X*** within the mentioned ***n*** dimensional space of source vectors ***j = 1 – m*** is therefore defined as well. However the state of the dependent TS property (value) ***f(X)*** of this variante ***x*** is not known, and the task is to estimate i.e. predict it. Such a task is not in general solvable by regression analysis, etc. [4].

Our approach to the solution of the mentioned task has been as follows. Although the ***n***-dimensional space is in question, above mentioned requirements led us to concentrate on possibilities how to estimate the value ***f(X)*** using only surrounding, i.e the closest and most similar TS source vectors. We have established as a crucial idea that the value ***f(X)*** can be interpolated from the values ***f(J)*** of those source variants ***j*** whose vectors ***x*** have the nearest distances ***d(x,j)*** and similarities ***sim (x,j).*** Given the maximum distance d_{max} and a distance function ***d(x,j)*** the mutual similarity between the couples of vectors ***j*** and ***x*** can be calculated as [2]:

$$sim(x,j) = 1 - \frac{d(x,j)}{d_{\max}}$$

The question is, how much vectors to take into consideration. The choice depends on the used way for interpolation . The idea mentioned above led as at the beginning to the approach based on interpolations within the triangle determined by the three end points ***J =***

A, B and ***C*** respectively related to the three ‘closest’ vectors. The results were quite promising, but we early found further potential of the third dimension “above” this triangle. Resulting model in a form of the tetrahedron ***J = A, B C*** and ***D*** respectively is shown in the Fig. 1 .

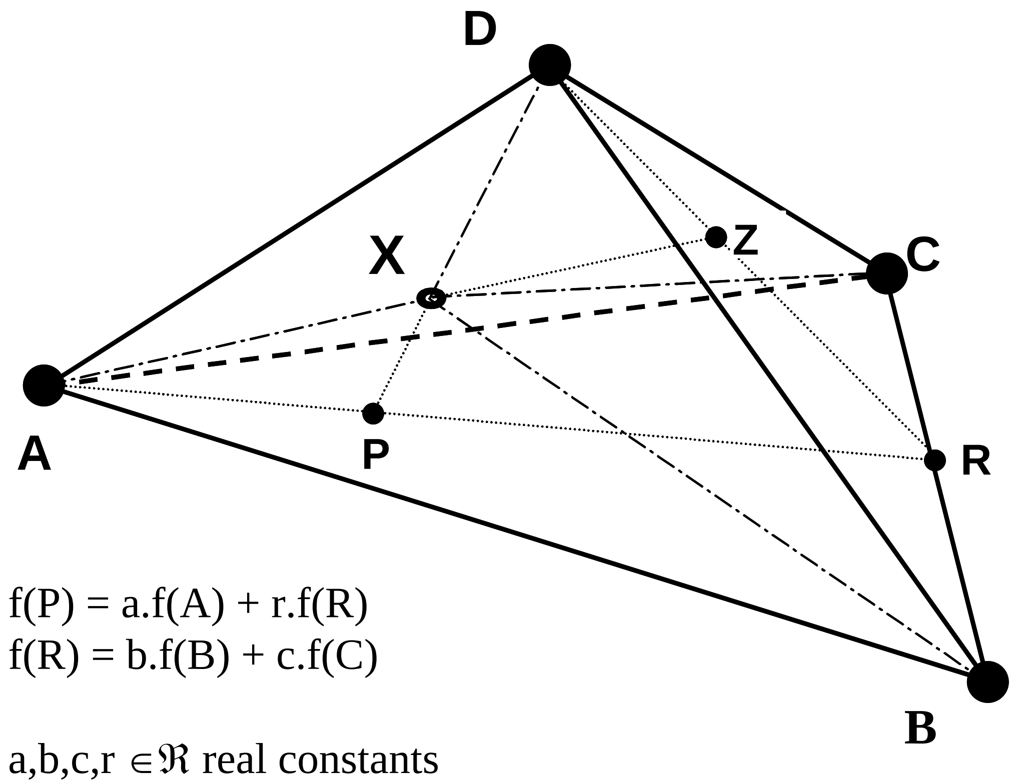

Fig. 1: Model of interpolation tetrahedron within n-dimensional space

The procedure of the destination of the value ***f(X)*** has been based on the sequential linear interpolations of the intermediate values between the individual pair of points, based on known values of functions at the apexes of the tetrahedron ***A, B, C*** and ***D*** with aid of subsidiary points ***P, R*** and ***Z***. The realisation of this strategy is possible both in graphical and numerical forms. Both methods have been used during development of mentioned algorithms [4].

3 Implementation

The method described above has been algorithmized and implemented on PC. Due to easy debugging, user-friendliness and large usage in practice the MS Excel 97 has been chosen as the first. In spite of that the algorithms are in the advanced development stage, the better friendliness of the programme is conspired hereafter.

4 Case Studies

The presented method has been tested on series of examples. The principle of testing was based on comparisons of couples of results achieved both precisely by analytical way and by presented interpolation method.

4.1 Example 1: The estimation of the mass of the cap.

The first example presents the estimation of one of the general TS property - mass of the machine part. As a typical machine part the cap with holes has been chosen. The exact value of the mass of a cap can be easily calculated to check the accuracy of the estimation. The shape of the cap is defined by 10 dimensions, D1-D6, L1-L3, N (Fig. 2), which, along with the density of material, define the mass of the cap. Let us have the base of ***n*** steel caps, whose parameters and masses are known. The masses of the new caps are then estimated in a way as mentioned above. By comparison to the exact calculated mass the accuracy of the estimation have been expressed as the accuracy coefficient. In the presented example 10 caps as the base have been stated and the masses of the next 5 caps have been then performed and compared with the calculated exact values (Fig. 3).

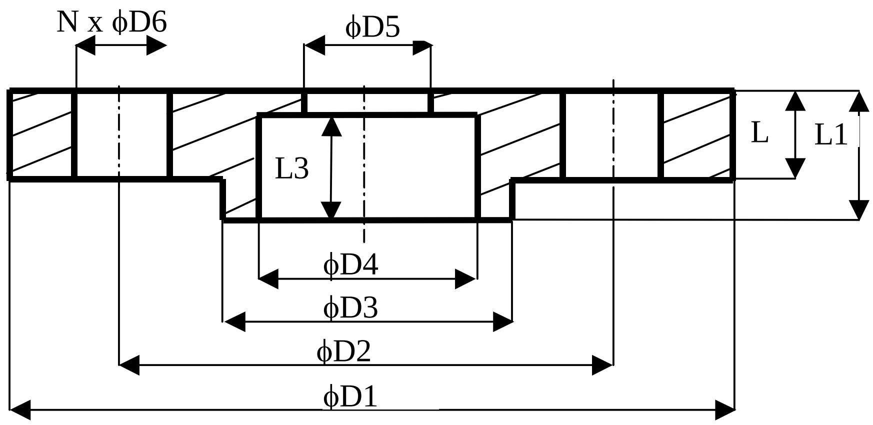

Fig. 2: Model of a cap

Cap	Input parameters										Mass		Accu-racy
	D1 [mm]	D2 [mm]	D3 [mm]	D4 [mm]	D5 [mm]	D6 [mm]	L1 [mm]	L2 [mm]	L3 [mm]	N [1]	m_{exact} [kg]	m_{interp} [kg]	
Base of the given caps (with exact masses)													
1	**55**	**49**	**40**	**35**	**30**	**4,3**	**16**	**12**	**14**	**6**	**0,138**	-	-
2	**42**	**32**	**26**	**22**	**15**	**4,1**	**15**	**10**	**11**	**4**	**0,087**	-	-
3	**45**	**38**	**31**	**26**	**22**	**3,9**	**18**	**14**	**16**	**5**	**0,119**	-	-
4	**64**	**57**	**48**	**44**	**20**	**4,5**	**17**	**12**	**15**	**4**	**0,184**	-	-
5	**72**	**62**	**54**	**47**	**38**	**4,3**	**19**	**11**	**14**	**6**	**0,253**	-	-
6	**80**	**68**	**65**	**55**	**30**	**4,5**	**20**	**15**	**18**	**5**	**0,366**	-	-
7	**30**	**25**	**20**	**16**	**10**	**3,1**	**14**	**10**	**12**	**4**	**0,043**	-	-
8	**85**	**76**	**67**	**60**	**44**	**4,7**	**25**	**20**	**22**	**6**	**0,489**	-	-
9	**110**	**100**	**90**	**80**	**50**	**4,9**	**20**	**15**	**16**	**6**	**0,662**	-	-
10	**56**	**50**	**40**	**35**	**30**	**5,1**	**17**	**15**	**12**	**6**	**0,177**	-	-
Next case caps (with comparison of exact and interp. masses)													
1	**60**	**50**	**40**	**35**	**18**	**4,3**	**15**	**10**	**12**	**6**	0,168	**0,17**	**0,98**
2	**55**	**49**	**40**	**35**	**30**	**4,3**	**16**	**12**	**14**	**6**	0,355	**0,36**	**1,01**
3	**74**	**65**	**58**	**50**	**38**	**3,9**	**22**	**12**	**15**	**5**	0,313	**0,31**	**0,98**
4	**40**	**30**	**20**	**18**	**12**	**2,5**	**11**	**8**	**9**	**3**	0,066	**0,07**	**1,06**
5	**96**	**86**	**76**	**68**	**40**	**4,3**	**20**	**14**	**16**	**8**	0,501	**0,52**	**1,04**

Fig. 3: Estimation of the masses of the caps

4.2 Example 2: The estimation of the relative cost of the threaded hole.

The data of the second presented example 'relative manufacturing cost of a threaded hole' have been taken from [1, p. 28]. Each variant is described here by its type and diameter and the manufacturing cost is a resulting property (Fig. 4). Let us consider that the above mentioned base of source alternatives is presented by the set of *n=20* cases ("•" points) randomly taken from the diagram and the estimated relative costs of the next 'new' 6 selected holes (Fig 5) have been then compared to those read from the diagram.

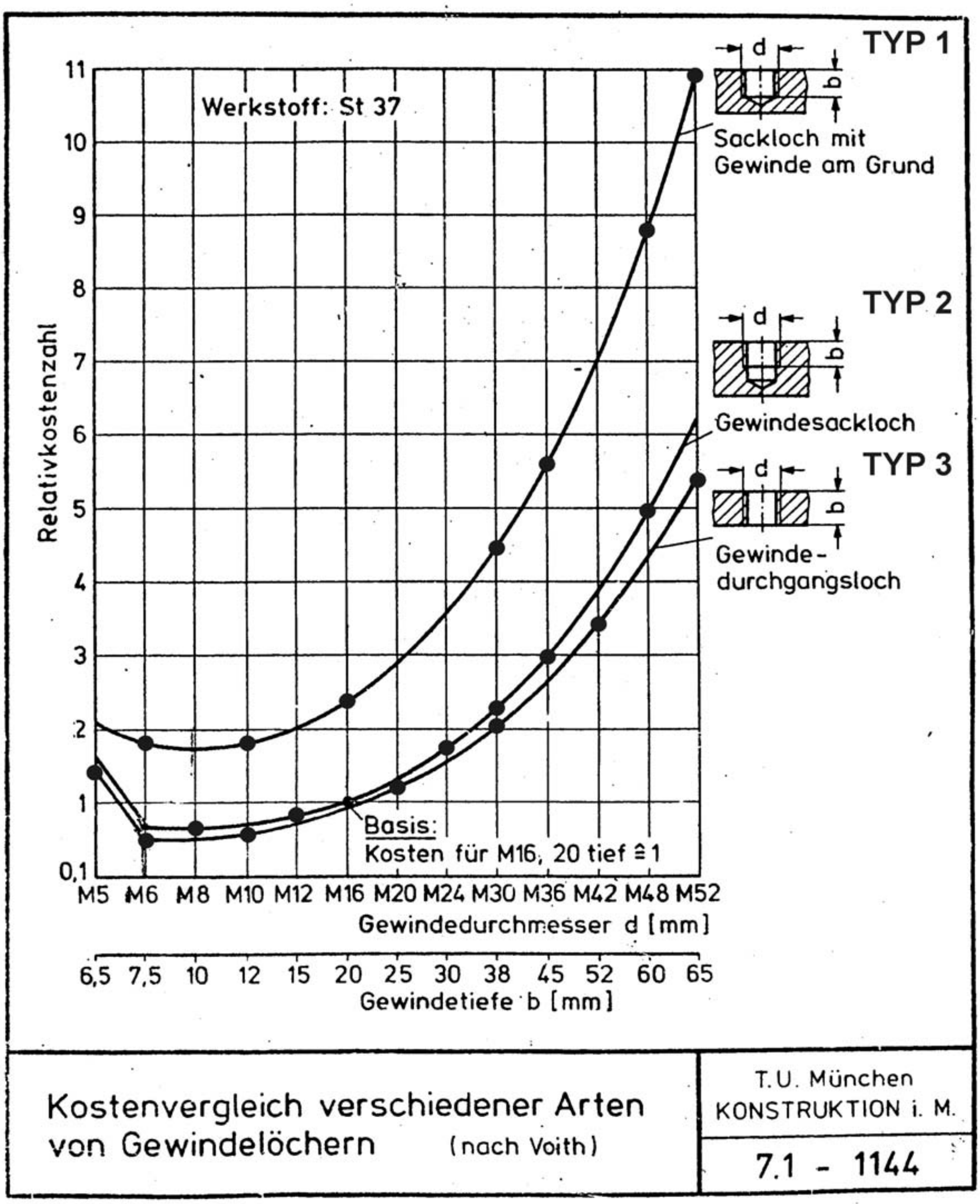

Fig. 4: Threaded holes with relative manufacturing costs

Threaded hole	Input parameters		Relative cost		Accuracy
	d [mm]	Type [1]	Cost $_{exact}$ [1]	Cost $_{interp}$ [1]	
Base of the given threaded holes (with 'exact' cost from diagram)					
1	6	1	1,8	-	-
2	10	1	1,8	-	-
3	16	1	2,3	-	-
4	30	1	4,5	-	-
5	36	1	5,7	-	-
6	48	1	8,8	-	-
7	52	1	11,0	-	-
8	8	2	0,8	-	-
9	12	2	0,9	-	-
10	16	2	1,0	-	-
11	24	2	1,8	-	-
12	36	2	3,0	-	-
13	48	2	5,0	-	-
14	5	3	1,4	-	-
15	6	3	0,6	-	-
16	10	3	0,7	-	-
17	20	3	1,2	-	-
18	30	3	2,0	-	-
19	42	3	3,4	-	-
20	52	3	5,4	-	-
Next case threaded holes (with comparison of 'exact' nad interpolated cost)					
1	12	1	2	1,97	0,98
2	42	1	7	7,25	1,03
3	10	2	0,8	0,8	1
4	30	2	2,4	2,4	1
5	8	3	0,65	0,65	1
6	24	3	1,5	1,52	1,01

Fig 5: Estimation of the relative manufacturing costs

5 Conclusion

The presented method for the estimation of the states of properties of new TS variants based on database of source variants seems to have practical utilisation. The requirement of only four needed source variants implicates the fact, that number of variants needed for the estimation may be lesser than the number of parameters determining these variants. From it follows that the presented method also enables to estimate the results when the number of needed source variants is lower than the number of independent variables. However, the more variants is available, the best selection of the suitable four assigned points and the higher accuracy of results are achieved. Next development and testing of the method including more extensive mathematical reasoning is assumed

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