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Interrelated Dimensional Chains in Predicting Accuracy of Turbine Wheel Assembly Parameters

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Abstract. The working capacity of any device primarily depends on the assembly accuracy which, in its turn, is determined by the quality of each part manufactured, i.e., the degree of conformity between final geometrical parameters and the set ones. However, the assembly accuracy depends not only on a qualitative manufacturing process but also on the assembly process correctness. In this connection, there were preliminary calculations of assembly stages in terms of conformity to real geometrical parameters with their permissible values. This task is performed by means of the calculation of dimensional chains. The calculation of interrelated dimensional chains in the aircraft industry requires particular attention. The article considers the issues of dimensional chain calculation modelling by the example of the turbine wheel assembly process. The authors described the solution algorithm in terms of mathematical statistics implemented in Matlab. The paper demonstrated the results of a dimensional chain calculation for a turbine wheel in relation to the draw of turbine blades to the shroud ring diameter. Besides, the article provides the information on the influence of a geometrical parameter tolerance for the dimensional chain link elements on a closing one.

1. Introduction

The calculation of dimensional chains is a necessary design, manufacturing and operational stage [1]. Dimensional chains are able to resolve the following tasks:

- setting geometrical and kinematic links between part dimensions, identifying nominal values for deviations and dimensional tolerances;
- establishing the accuracy standards and development of technical specifications for the assembly and its elements;
- calculation of interoperational dimensions, allowances and tolerances, etc.

A dimensional chain is a total of dimensions making up a closed loop and directly participating in the set task resolving [2].

The aircraft industry stipulates for the engagement of so-called dimensional chains in most of the calculations which makes a task significantly harder to resolve. To do it, one needs to adopt a special approach.

The present article aim is to address the issue of the enhancement of the air cluster assembly technology by means of computer calculations.

2. Problem statement

One of the relevant examples of an assembly unit with the presence of interrelated dimensional chains is a turboshaft engine wheel.

The turbine assembly is implemented in compliance with the following stages:

1. After mechanical treatment, interface parts "blade-disc" are divided into 3 groups [3, 4].
2. Each blade weight is determined with a certain degree of accuracy and put in pairs in the order of descending weight.
3. For each pair "blade-disc", one needs to determine the size of gaps in the interface. As it is quite difficult to determine the size of gaps directly, one determines a gap indirectly. Each blade is separately put into a specially designated groove, and then one determines the tangential swing value at the set radius by means of swinging it along the disc transverse plane (by a so-called "swing"). The control of blade root contact surfaces fit into the disc grooves is performed with the help of zinc oxide [5, 6]. Zinc oxide is applied onto the blade root, then dried and the blade passes through "its" groove. In case of insufficient contact (visual), the fir-tree blade attachment is refined by means of grinding [7, 8].
4. The draw between the platforms is assessed indirectly as follows: One sets a permissible value for a shroud platform turning inside an assembled wheel in relation to the shroud platform turning before the assembly. For this purpose, the shroud platform turning in relation to the attachment platform is visually checked for each blade before its assembly.
5. After the parts have been prepared for the assembly, one performs the first technological wheel assembly. The disc is put on a special horizontal table and fastened with the bolts. The table has an opportunity to move vertically in relation to a fixed table on which bearing plugs are fastened; the number of such plugs is equal to the number of disc grooves for blades. The plugs are located in the middle of the disc grooves. The movable table (with a disc) is lowered so as to make the plugs sink to a certain depth. Further, all the blades are manually put into the disc grooves until they stop against plugs. Afterwards, one performs a set of operations to elevate the table with a disc for a certain pre-set value and a gradual blade tapping (manually with the help of a fibrous hammer).
6. Final control stage. At this stage all the output geometrical parameters are controlled. To control the draw, one needs to check the shroud platform turn in relation to attachment platforms, the results for each blade are compared with the results obtained at the stage 4 [9, 10].

The assembly lasts for quite a time. Applying the preliminary computer calculations for such parameters as the gap between shroud platforms of adjacent blades, the gap between attachment platforms of adjacent blades and the draw between the contact surfaces of blade shroud platforms will make the assembly more efficient due to reduction of the operation time while improving its quality.

To get a functional unit subassembly, it is necessary to ensure the commensuration of assembly parameters at the actual assembly process; in particular, they should be in the tolerance range and have the values specified in the technical specification of the drawings for the parts used for such assembly [11]. In case of the turbine wheel, the following values are important: gap between shroud platforms of adjacent blades, gap between attachment platforms of adjacent platforms and draw between the contact surfaces of blade shroud platforms. If assembly parameters deviate from the specifications, the assembly may result in a wedge of 5-7 blades.

Let us consider dimensional chains by the example of the draw at blade shroud platforms. Figure 1 shows a dimensional chain with a gap between shroud platform surfaces.

The figure demonstrates a part of the disc with two blades. The dimensional chain starts acting from the center of adjacent blade platform contact on the shroud surface towards the attachment plane on one of the blades (V1). Further, the chain is going the same way on the shroud surface towards the attachment end plane (V2). Then it passes to the groove center on the disc rim (V3). At this moment a blade swing is registered. To do this, one uses a vector with zero coordinates and having only a turning angle deviation. Further, the chain passes through the center of the turbine wheel rotation axis (V4) and goes to the adjacent blade disc groove axis (V5). Here one also needs to account for a blade swing in the attachment. The chain is moving towards the attachment end plane for a so-called draw diameter (V6). Being located on the shroud platform surface, the vector dimensional chains passes along the attachment axis towards the attachment plane (its center, V6). The chain finishes at the blade interface (with the next blade, V8).

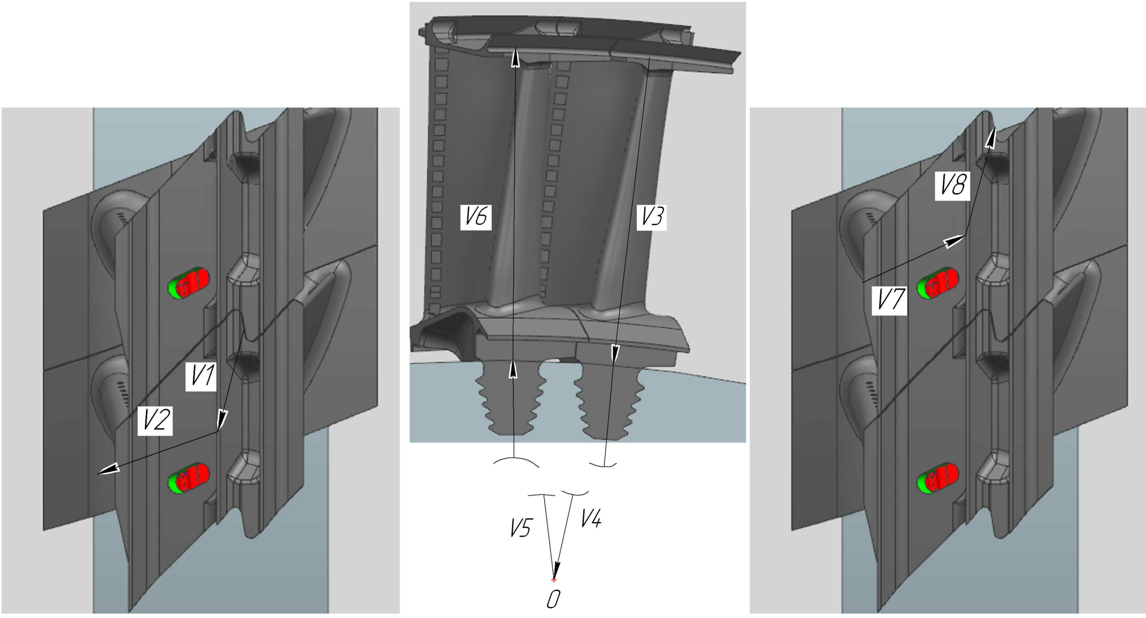


Figure 1. Visualization of turbine wheel dimensional chain (blade-disc connection).

Such dimensional chain has a three dimensional nature. In compliance with [2], a dimensional chain is called a spatial one if its links are not parallel and are located in non-parallel planes. In similar works, the authors suggests the solution for such a chain in the Vector programme using a turn of an axial plane for the correlation of all vectors.

3. Solution algorithm

The present algorithm describes the solution algorithm from the point of view of mathematical statistics implemented in the package Matlab.

The software code is written on the basis of the programme "Vector" used for the calculation of dimensional chains and has the same purpose.

The algorithm for the stated programme solution consists in finding out the closing link of the dimensional chain studied above and determining the value scattering field.

Figure 2 shows the algorithm for the dimensional chain algorithm in the form of a diagram.

To perform correct calculations, one enters the input data of calculation parameters into the programme. One should enter data on 14 positions for each vector: work plane type (XY, YZ, XZ), type of coordinates in which the dimension is set, the first coordinate values, the second coordinate value, lower and upper limits of the second coordinate, rotational angle of the coordinates system, lower and upper limits of the rotational angle of the coordinates system, parameter of the first coordinate distribution, parameter of the second coordinate distribution, rotational angle distribution parameter. The dimension (vector on a plane can be set in several ways: by means of coordinates (x,y), (x,z) or (y,z), a vector module and an angle.

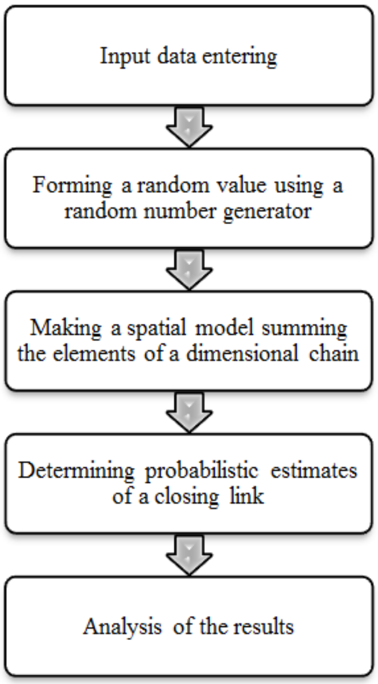


Figure 2. Solution algorithm for dimensional chain calculation.

The second stage to resolve the chain solution algorithm after entering the calculation input data is to determine each of the chain link with the help of a random number generator. Relying on the experience of the researchers in the field, let us choose a normal law of the values distribution. In such case, the function of value probability distribution is written as equations (1),

$$y = \frac{1}{\sigma_x \cdot \sqrt{2\pi}} \cdot e^{-\frac{(x-m_x)^2}{2\sigma_x^2}} \tag{1}$$

where x – random value,
y(x) - probability of a random number taking the value x,
m_x – mathematical expectation,
σ_x – mean square deviation.

The third and fourth stages of the algorithm work are sum of a vector dimensional chain and getting the results of a probabilistic nature - the chain closing link value matrix.

Such algorithm is also applied to the resolving of the problem to determine a probabilistic gap between the shroud platforms of adjacent blades and the gap between the attachment platforms of adjacent blades as well as to resolve any dimensional chain.

4. Results and discussion

The calculations in compliance with the described algorithm allow us to obtain the value of a closing link - the blade width at the shroud diameter. It gives us an opportunity to judge about a probable draw in the joint of the shroud platforms of two adjacent blades and its value.

The calculation result is formed as a table with the vector end coordinates.

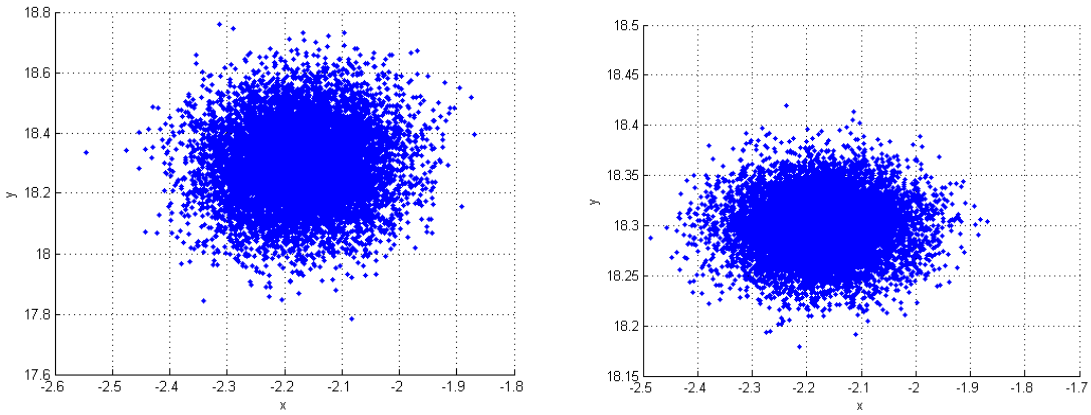
In compliance with the input data presented in the Table 1, the authors modeled a dimensional chain. The modeling results are provided in the graphical modes (Figure 3, a).

Within the research, the authors conducted checking calculations in terms of the influence exerted by the tolerance size of some values of the geometrical parameters given for dimensional chain link elements on the final result of calculations.

The results demonstrated that the closing link of the considered turbine dimensional chain is mostly influenced by the blade turn in a fir-tree blade attachment, in particular, by a so-called "swing".

Table 1. Input data

Dimensional chain pitch number	Type of coordinates to set a dimension	First coordinate value	First coordinate lower limit	First coordinate upper limit	Second coordinate value	Second coordinate lower limit	Second coordinate upper limit	Rotational angle of the system of coordinates	Rotational angle lower limit	Rotational angle upper limit
1	0	0	0	0	0	0	0	88	-0.08333	0.083333
2	1	-17	-0.05	0.05	172	0	0	82	-0.16667	0.166667
3	1	24.35	-0.05	0.05	8	0	0	8	0	0
4	0	0	0	0	-87.95	-0.1	0.1	0	0	0
5	0	0	0	0	-334.4	-0.15	0.15	90	0	0
6	0	0	0	0	0	0	0	82	-0.06667	0.066667
7	0	0	0	0	0	0	0	94.33722	-0.01667	0.016667
8	0	334.4	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	98	0	0
10	0	0	0	0	0	0	0	90	0	0
11	0	-87.95	-0.1	0.1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	262	0	0
13	1	24.35	-0.05	0.05	8	0	0	98	-0.16667	0.166667
14	1	17	-0.05	0.05	352	0	0	2	-0.08333	0,1
15	0	0	0	0	5.65	-0.5	0	0	0	0



a b

Figure 3. Closing vector scattering field: a – including "swing", b – without "swing"

The results demonstrated the closing link of the considered turbine dimensional chain is mostly influenced by the blade turn in a fir-tree blade attachment, in particular, by a so-called "swing".

Figure 3 (b) shows the result of closing vector scattering field without "swing".

5. Conclusion

The calculation results allow predicting a probability of a draw occurrence as well as the probability of its deviation from technical specifications.

The relevance of a turbine dimensional chain calculation consists in the necessity to improve the assembly technology for this assembly unit. At the production site the turboshaft rotor assembly with the shroud diameter can be complicated by seizure of adjacent blades. The draw dimension value evident during the seizure at working surfaces can exceed the permissible value set in the design documents. Exceeding the draw value can result in a partial destruction of shroud platform contact surfaces in the course of the assembly unit operation. Such problem results from the broad ranges of tolerance for the blade dimensions. It can be resolved by means of setting corrective measures formed as a result of the calculation of assembly dimensional chains.

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