# Creating of genetic algorithm model for optimization of jet engine components

## Budowa modelu algorytmu genetycznego na potrzeby optymalizacji elementów konstrukcji silnika turbinowego

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**In this paper authors show results of optimization of compressor discs in turbine engines. The problem of optimizing the disc thickness brought to the NP-complete problem, and solved it by using one of the genetic algorithms – evolutionary algorithm. Correctness of model and optimization algorithm were constantly checked. At the end of this paper, compressor disc created due to traditional technology and disc created by BLISK technology were compared.**

**KEYWORDS: optimization, turbine engine, evolutionary algorithm, BLISK**

The possibility of creating a universal algorithm for optimizing the compressor disc in turbofan jet engine was analyzed. Based on a review of the selected current turbofan engine designs, their most important parameters were determined for compressor optimization. An algorithm in MATLAB language, using FEM to calculate stresses, was created. A program written in GRIP uses FEM to determine limitations of the function optimized by evolutionary algorithm. Due to the rotor complexity and limited validation of the algorithm performance, authors were focused on the calculation and optimization of a single disc (fig. 1).

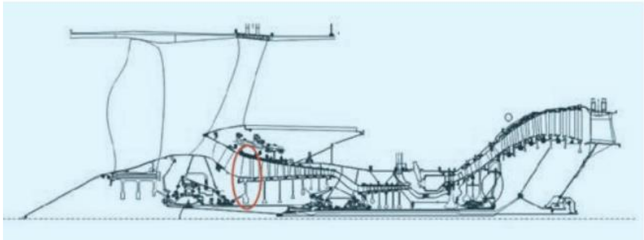

Fig. 1. Cross-section of Trent XWB engine [1]; optimized in red

Among the trends in design components (fig. 2),as a base engine Trent XWB was chosen for further calculation (fig. 1). The first stage of the medium pressure compressor was optimized.

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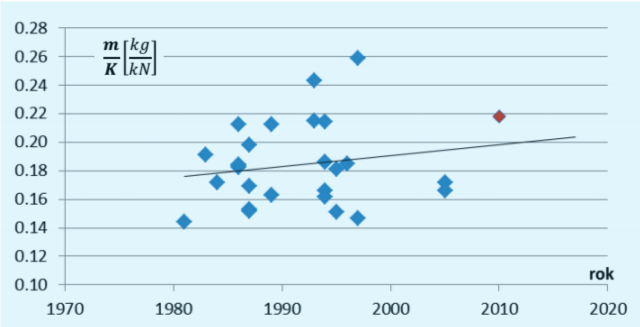


Fig. 2. Changing the mass to thrust ratio of selected engines over the years; in red - Trent XWB

Currently the multistage rotors in BLISK technology are being implemented more and more often. In such stages blades and disc form one unit and cannot be easily disassembled. Replacement of damaged blades or repairs of stages made in BLISK technology usually involve cutting out a damaged part and, for example, welding a new one. As these stages do not have locks, smaller rims can be used. This reduces the mass of the outer part of the disc, and consequently also the force resulting from its rotation. This helps to reduce the thickness of both the disc and its hubs. In addition, adjacent stages made in BLISK are usually combined with friction welding, which also gives savings on the mass.

### Parameters affecting the loading rate of the rotary discs

The rotary discs are loaded with different forces. The purpose of the disc in the case of the compressor is to transfer work and forces from the shaft to the palisade of blades. Depending on the source of the loads, these can be divided into three groups:

- the loads from the flow working medium - these include the aerodynamic force caused by the pressure difference operating on the blade and lateral forces operating on the surface of the disc;
- mass forces;
- thermal loads generated by the temperature gradient during the operation of the flow machine.

In order to determine the most important parameters in the case of the disc load, the general equation of the differential rotating disk of variable thickness [2] is derived.

$$\frac{d^2u}{dr^2}+\frac{1}{r}\frac{du}{dr}\left[r\left(\frac{1}{h}\frac{dh}{dr}+\frac{1}{E}\frac{dE}{dr}\right)+1\right]-\frac{u}{r^2}\left[1-\nu r\left(\frac{1}{h}\frac{dh}{dr}+\frac{1}{E}\frac{dE}{dr}\right)\right]=-Ar+(1+\nu)(\alpha T)\left[\frac{1}{h}\frac{dh}{dr}+\frac{1}{E}\frac{dE}{dr}+\frac{1}{(\alpha T)}\frac{d(\alpha T)}{dr}\right] \quad (1)$$

where: $u$ - displacement (m); $r$ - current radius (m); $h$ - disc thickness (m); $E$ - Young's modulus (Pa); $\nu$ - Poisson's ratio; $\alpha$ - coefficient of thermal expansion; $T$ - temperature (K); $A=\rho\Omega^2\frac{1-\nu^2}{E}$; $\rho$ - density $\left(\frac{kg}{m^3}\right)$; $\Omega$ - angular velocity $\left(\frac{rad}{s}\right)$.

In the boundary-initial conditions, inner and outer radii were not transparent. The forces originating from the blade rim in the discussed equation are included as a boundary condition for $r = r_{zew}$ in the form of a drag resulting from the blade mass, together with the lock and the rim necessary to place a blade. The influence of ΔT was not taken into account because in the first stages of the compressor its importance for material properties and thermal stresses can be neglected. This algorithm enables the implementation of the influence of the temperature gradient on the material properties of the disc.

**Strength analysis of the compressor disc**

The method proposed in [3] was used to determine the stresses. It approximates the disc by one-dimensional elements of a conical shell of linearly varying thickness. The single element used for calculations is shown in fig. 3. This method was modified based on the source [4]. In addition, using [5,6], the size and weight of the lock part disc made in traditional technology and BLISK were set down.

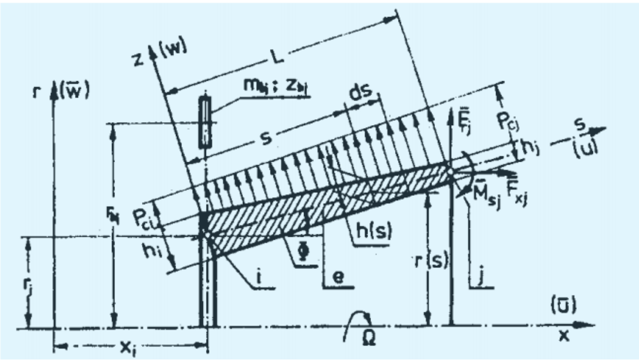

Fig. 3. Geometric dimensions and loads of a one-dimensional conical shell element with linearly varying thickness [3]

In order to verify the correctness of the program based on FEM, results for the test disc were compared with analytical results (fig. 4 and fig. 5). Fig. 5 shows the relative error for each element. It is clear that it does not exceed 0.6%, which indicates a high accuracy of the method.

**Selection of optimization method**

Minimizing mass of the disc was adopted as the objective function in selected optimization method. To satisfy the condition of endurance, penalty function was applied. Optimization method was chosen based on studies [7,8].

Due to the random factor in non-deterministic algorithms, it cannot be guaranteed that the algorithm has found a global minimum. However, approaching it or finding a satisfactory local minimum is highly likely.

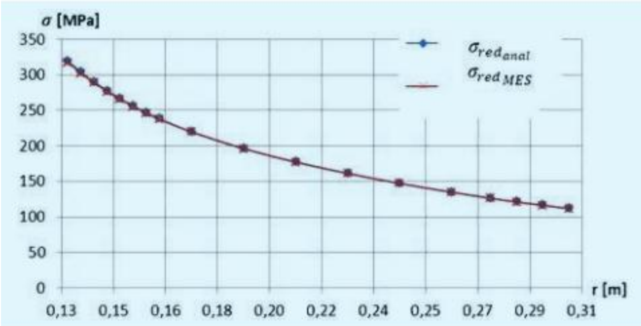

Fig. 4. Reduced stresses as a function of the current radius for the straight disc

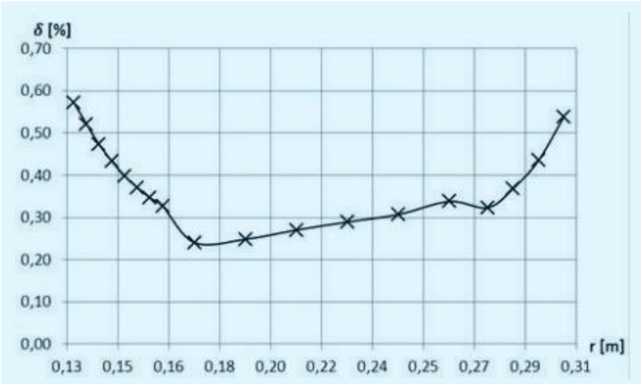

Fig. 5. Relative error δ for reduced stresses as a function of the current radius for a straight weighty disc

Genetic algorithm is based on a few basic steps and operates on discrete values. At the beginning discrete nature of the task is defined and decided how and by how many bits to describe a single solution. The next step is to draw the initial generation solutions. Subsequently, solutions that will cross, are selected.

For this purpose, the method of the tournament was applied. Of all the solutions, a few were drawn, and among them, by the method of the tournament, the best two were selected. These solutions exchange with each other the appropriate bit parts, creating new solutions. These actions are repeated. The next step is to select the part of the solutions, in which the random number of randomly selected bits are negated. This procedure delays the domination of solutions that correspond to local minima and increase the probability of achieving a global minimum. The next step is to create a new generation of solutions from the tournament winners, the solutions created by their crosses, and the solutions that use negatives.

**Calculation results**

The main aim was to compare the shape and weight of the optimized blade made in the classical and BLISK technology. For this purpose, the two discs were simplified for numerical calculation. In the disc made in BLISK technology, locks were omitted. It was assumed that the optimizing part of the disc made in BLISK will be longer for the height of the lock. Other parameters of the discs remain unchanged. The differences in the dimensions of geometrical models of the disk were shown in fig. 6.

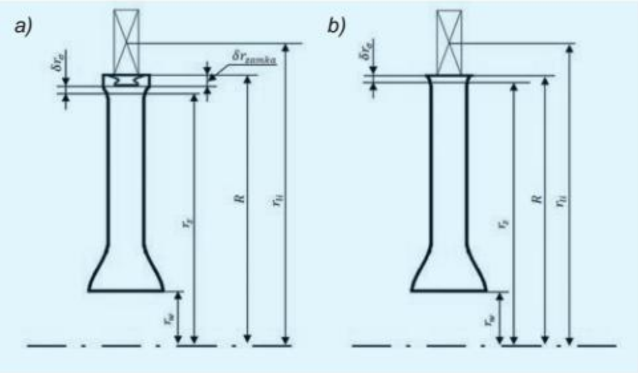


Fig. 6. Shape geometry model: *a*) made in traditional technology and *b*) blade made in BLISK technology

The results of the optimization are presented in fig. 7. It shows the cross-sections made in traditional (red) and BLISK (blue) technology. The optimization process created a hub. It can be seen that the blade made in BLISK technology is narrower and above all has a smaller hub. In addition, the weight of the optimized part is about 1 kg lower (with the optimized BLISK disc about 9.4 kg) than the disc made in classical technology. This difference increases as the difference in masses of non-optimized parts is taken into account. The weight of the locker part of disc is approximately 3.5 kg, which, with a total weight of optimized disc (BLISK 14.5 kg and traditional 19.1 kg), gives a weight gain on the whole piece, with a change in technology of the order of 4.6 kg.

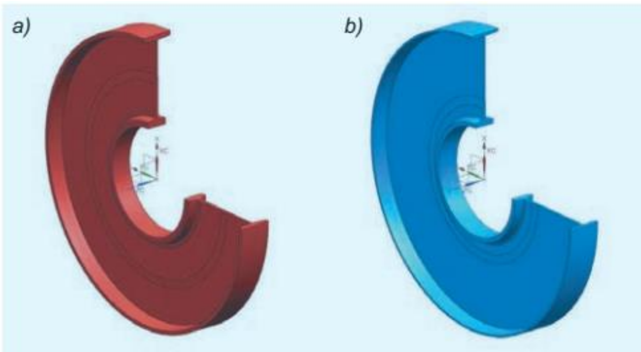


Fig. 7. Axonometric projection of three-dimensional disc: *a*) made in traditional technology, *b*) made in BLISK technology

Fig. 8 shows a cross section of the disc. The dark disc was made in the traditional technology. The contrast highlights the differences.

To verify the accuracy of all results, i.e. if the geometry meets the strength criterion, the strength analysis in the Siemens NX 7.5 program were tested. In the classical disc the stress distribution was relatively homogeneous, indicating that it was optimized in a fairly good way. In the BLISK disc stresses were clearly the nature of decreasing with increasing current radius of the current calculation. This is because the minimum permissible disc thickness has already been reached for the eighth of the twelve elements.

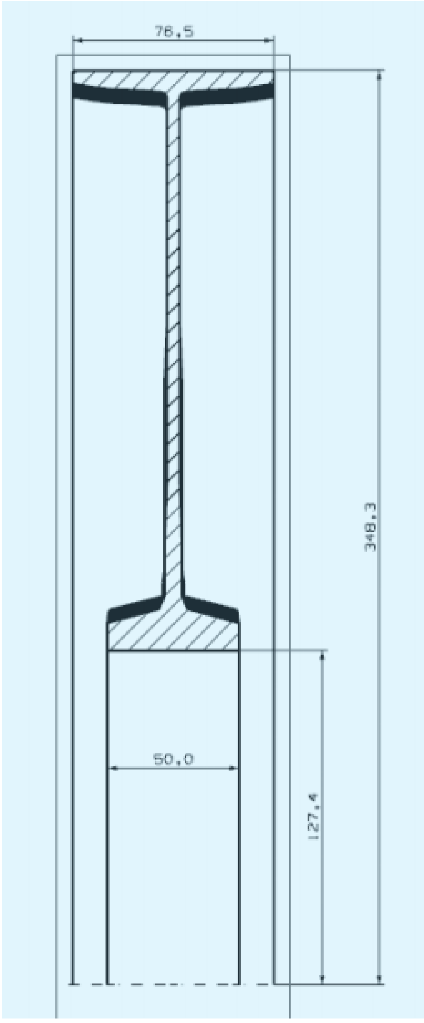


Fig. 8. The disc of the blade made in traditional (dark) technology and the disc made in BLISK technology (hatched). The BLISK disc is in the foreground.

## Conclusions

The proposed genetic algorithm, using FEM, despite its simplicity, achieves results consistent with results obtained by other methods. Accuracy is the greater, the larger the disc is. The genetic algorithm provides a relatively good quality design solution. The entering of a random element can extend the operating time. The advantage of the algorithm is a big chance to find the global minimum.

Weight gain with a technology change in making disc could have been anticipated, however, the size of difference is surprising. Based on the disc optimization it can be concluded that the greatest impact on the disc mass when a ratio of the mass part of the rim occupied by the stages and the total mass of the disc, as well as the size of the rim load.

The next stage of work in this area will be the increase of the speed in the algorithm operating process.

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