AUTOMATIC STRENGTH CALCULATION OF TURBINE BODY AND ROTOR PARTS


In the design and manufacture of turbine parts, many calculations are required for finding optimum parameters providing the best stress-strain states of these parts. Thus, the development of special algorithms and programs that allow fully automatic computer design of certain typical parts is very important since they, on the one hand, obviate the compilation of specific programs reflecting the geometry, loading, materials, etc., of individual parts, and, on the other hand, allow these programs to be utilized by less skilled personnel.

Here we discuss problems concerning the automation of strength calculations of structural body and rotor parts of turbines which constitute a system composed of cylindrical and conical shells linked by disks, or of successively joined toroidal, conical, and cylindrical shells. Such elastic systems operate in a variable temperature field under the action of centrifugal forces, nonuniform pressure, and boundary conditions. To such systems belong, in particular, the rotor drum (Fig. 1a) and the stator (Fig. 1b).

The design of such parts is based on the method of numerical solution of static boundary problems of orthotropic laminar bodies of revolution with an M-220 digital computer [1, 2], whose algorithm consists of a standard and nonstandard portions. The standard part of the algorithm includes input data processing, numerical solution of the boundary problem, and the calculation of all factors affecting the stress-strain state of the structure. This part of the solution is fully automatic. The nonstandard portion depends on parameters describing the geometry, mechanical properties of the material, the load, temperature, and boundary conditions, and must be specifically programmed for each concrete problem.

The discrete orthogonalization approach, described by S. K. Godunov, on which our method is based, affords a consistent computing process as applied to the solution of static equations of bodies of revolution.

The effectiveness and high accuracy of the discrete orthogonalization method has been proved in specific examples [1].

Here we describe an algorithm which on the basis of minimum numerical input information allows automatic programming of the design of the above-mentioned structural parts under axisymmetrical loading.

Accordingly, solutions are obtained for five classes of problems on the deformation of thin isotropic shells of revolution of variable stiffness subjected to internal pressure, centrifugal forces, temperature fields, and boundary loading.

The considered structural parts have the following middle surfaces: conical surface; conical surface with two cylindrical surfaces connected to it on both sides, cylindrical surface with two conical surfaces on both sides, toroidal surface, toroidal surface with a cylindrical surface connected to it, and conical surface.

The geometry of the middle surface of the considered shells (Figs. 2 and 3) is specified as follows: a) for the cylindrical part, by the radius of parallel circle and by the length of the meridian; b) for the conical part, by the angle of taper, the initial radius, and the length of the meridian; c) for the toroidal
Fig. 1. Structural parts of rotor (a) and stator (b).

part, by the angle of curvature of the meridian, the distance from the meridional circle center to the axis of revolution, and by angles specifying the beginning and end of the meridian.

Assume that for shells consisting of cylindrical and conical parts only, the thickness h, elastic modulus E, the coefficient of linear thermal expansion α_t, and pressure P are given for a certain number of points on their middle surface. It should be noted that between the given points the above factors vary linearly. In shells containing a toroidal portion, the thickness of the toroidal and cylindrical portions is assumed to be constant, and that of the conical portion to vary linearly. Let us also assume that at all points of each cylindrical, conical, and toroidal portions that comprise the shell the Poisson ratio ν and the material density ρ are constant, and that the temperature T of the entire shell does not vary with thickness.

A general method of numerical solution of boundary problems for shells of revolution acted upon by asymmetric forces has been given in [1, 2], where this class of problem is described by a system of differential equations of the form

$$\frac{dN}{ds} = A(s) \overline{N} + \overline{f}(s)$$

(1)

with given boundary conditions

$$B_1 \overline{N} = \overline{b}_1 \quad (s = s_{in});$$

$$B_2 \overline{N} = \overline{b}_2 \quad (s = s_{fin}),$$

(2)

where $\overline{N} = \{N_X, N_Z, \dot{S}, M_S, u_X, u_Z, v, s\}; B_1$ and $B_2$ are 4 x 8 square matrices; and $\overline{b}_1$, $\overline{b}_2$ are column vectors.

The problem discussed in this article can be solved with the aid of this method assuming the harmonic number $k = 0$.

According to the problem formulation, the given parameter values can be represented as follows.

The middle surface geometry of the shell is given by

$$r = r_{in} + (s - s_{in}) \sin \alpha$$

(3)

(for the cylindrical and conical portions, see Fig. 2);

$$r = R_o + r_o \sin \varphi;$$

$$\left(\frac{\pi}{2} - \alpha_2 \leq \varphi \leq \alpha_2 + \pi\right)$$

(4)

(for the toroidal portion, see Fig. 3), where $r$ is the distance from the middle surface point to the axis of revolution; $s$ is the current length of the meridian arc; $r_{in}$ and $s_{in}$ are the radius of the parallel circle and