BBC
BROWN BOVERI

Welded Rotors for Steam Turbines

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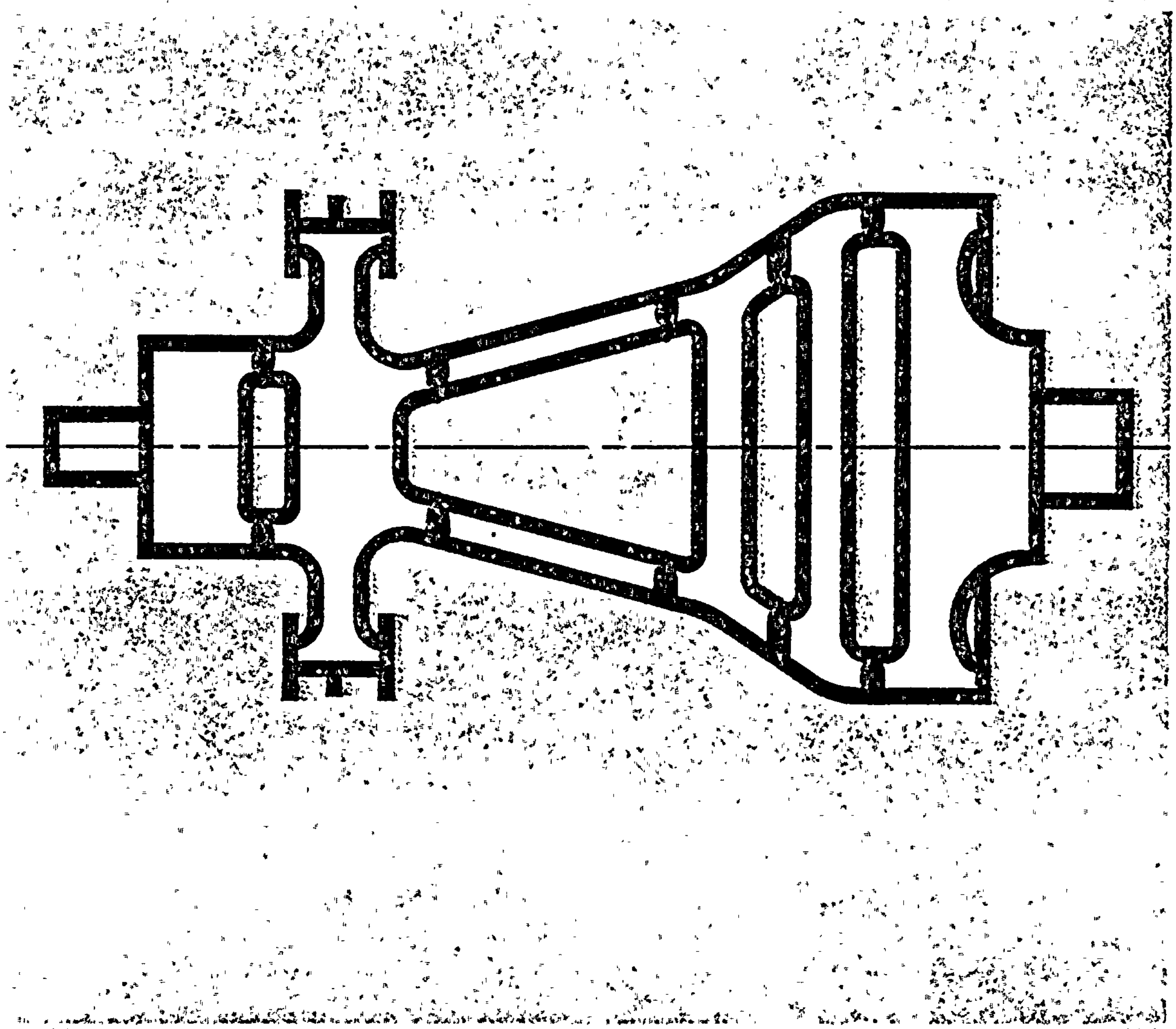

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Rotors for large steam turbines

The rotors for all large BBC turbines consist of a number of disks welded together to form a single solid unit. The high-pressure rotor of a large turbine as shown in Fig. 4 contributes 440 MW to the total turbine-generator output of 1350 MW.

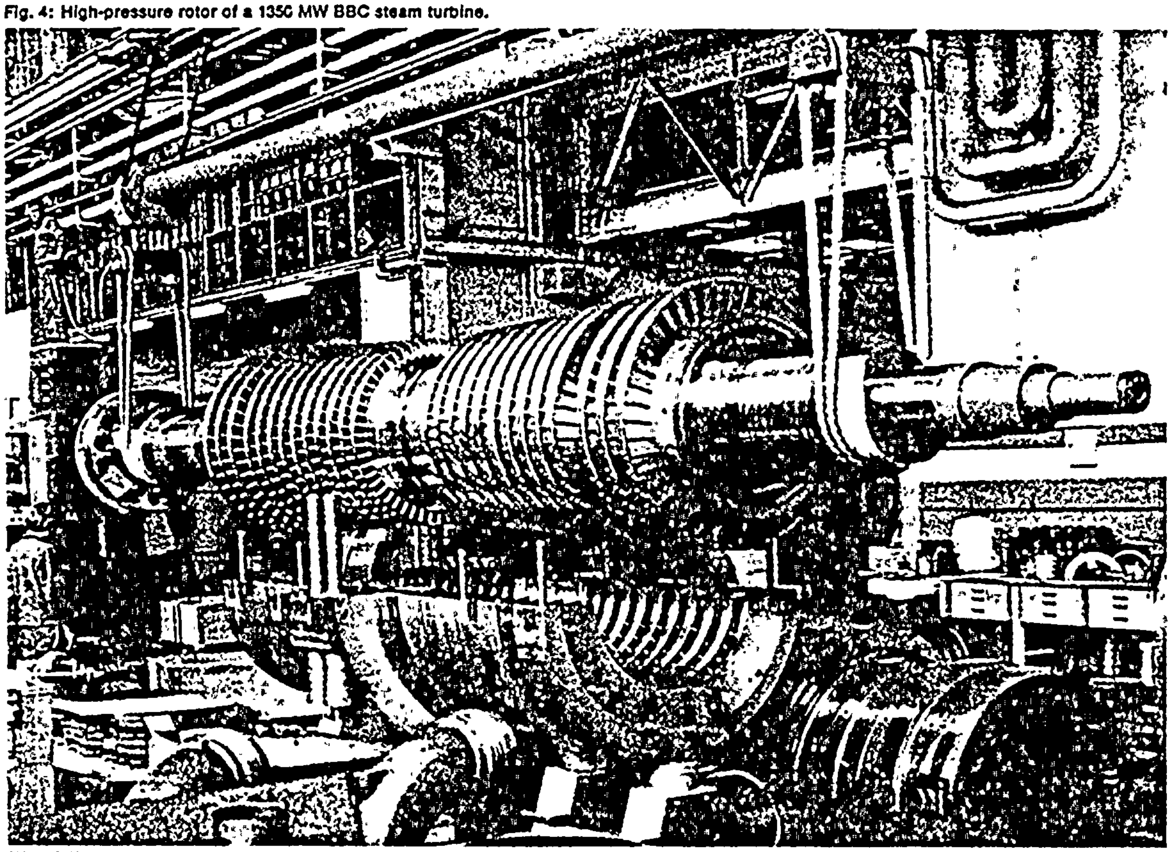
When building saturated steam turbines for nuclear power plants with an output of about 1000 MWe, the large component weights of 1800 or 1500 rev/min units become very important. In the low-pressure section for example, rotor weights between 150 and 200 tons and even higher are not unusual. With these large rotors the Brown Boveri welded disk design has a very important advantage. The individual rotor components still have moderate weights and the relatively small cross-sections allow the material to be thoroughly forged. Thus a high quality steel is guaranteed with a reduced risk of rejection.

Fig. 5 shows the welding of the low-pressure rotor of a 1000 MWe turbine for a nuclear power plant, and Fig. 6 shows the same rotor after welding and annealing.

The rotor weld and the welding procedure

Fig. 7 shows the various stages of development of the weld preparation during the last 40 years. The deep weld technique adopted for today's rotors has been used since about 1958 (Fig. 7d). Using this procedure and BBC's advanced welding methods a rotor is produced where the stress values in the welded areas are similar to those in the base material of the forged disks. Regular tests on rotor welds provide a solid statistical background to the welded rotor design. Microsections through rotor welds (Fig. 8) are carried out to determine the quality of the weld, the extent of the base material affected by the welding procedure and the mechanical properties of the weld material.

Fig. 4: High-pressure rotor of a 1350 MW BBC steam turbine.



Introduction

During the first two decades of this century, Brown Boveri used solid forged rotors for small turbines, and built-up rotors, consisting of a number of disks shrunk on to a central shaft, for larger units. For small machines the solid forged rotor is still standard, but for the large machines BBC subsequently discarded the shrunk disk design because of its higher stress levels. Articles from a number of independent sources deal with the stress levels and quality of this type of rotor [1, 2, 3].
After 1930 a design was adopted using a number of disks welded together to form a solid rotor. Thus all the risks inherent in large one-piece forgings were avoided and a high standard of fault detection was achieved, since the individual disks delivered by the steelworks are relatively small and can thus be very thoroughly tested.

Rotors of medium-sized steam turbines

Fig. 1 depicts the cross-section through the rotor of a 60 MW condensing turbine and clearly shows the forgings from which the rotor has been built up. The individual forgings are rough machined and ultrasonically tested at the steelworks, and in addition mechanical tests are carried out on pieces from each disk before delivery is made, to ensure that the mechanical characteristics are achieved. These tests determine the tensile strength, impact strength and yield point of the material.
All the disks are subjected to further standard inspection procedures in the workshops, including chemical analysis, tensile and impact tests, before machining commences. In addition the disks are ultrasonically examined for any internal flaws, such as cracks or inclusions. Only when confirmation has been received that all tests have been passed does premachining commence. This consists of turning the inner contour of the disk and the weld preparation contour. The condition of the rotor during this stage of manufacture can be seen in Fig. 2. After welding and machining, the rotor has the shape shown in Fig. 3.

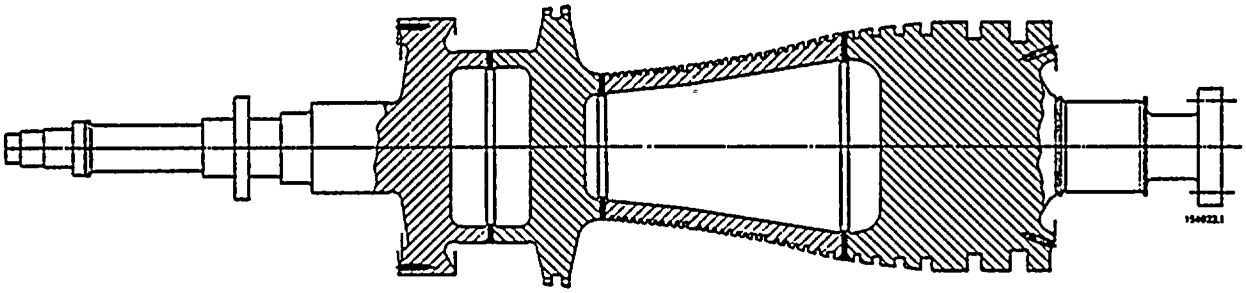


Fig. 1: Section through the rotor of a 60 MW condensing turbine.

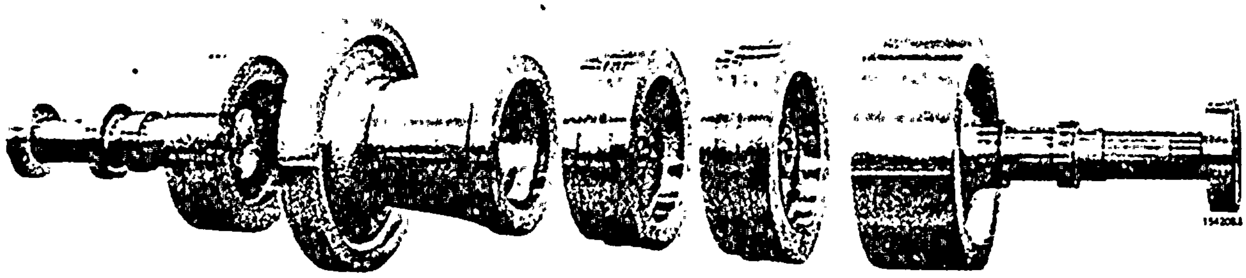


Fig. 2: Stacking the individual rotor disks in readiness for welding.

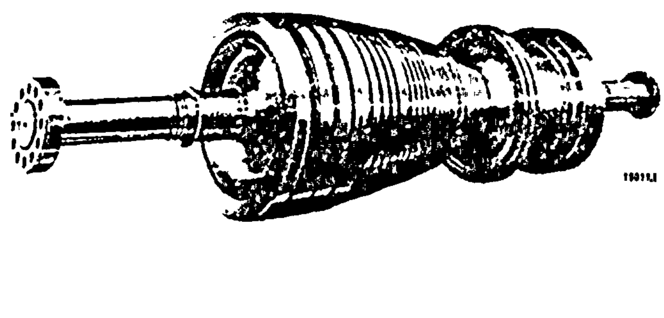
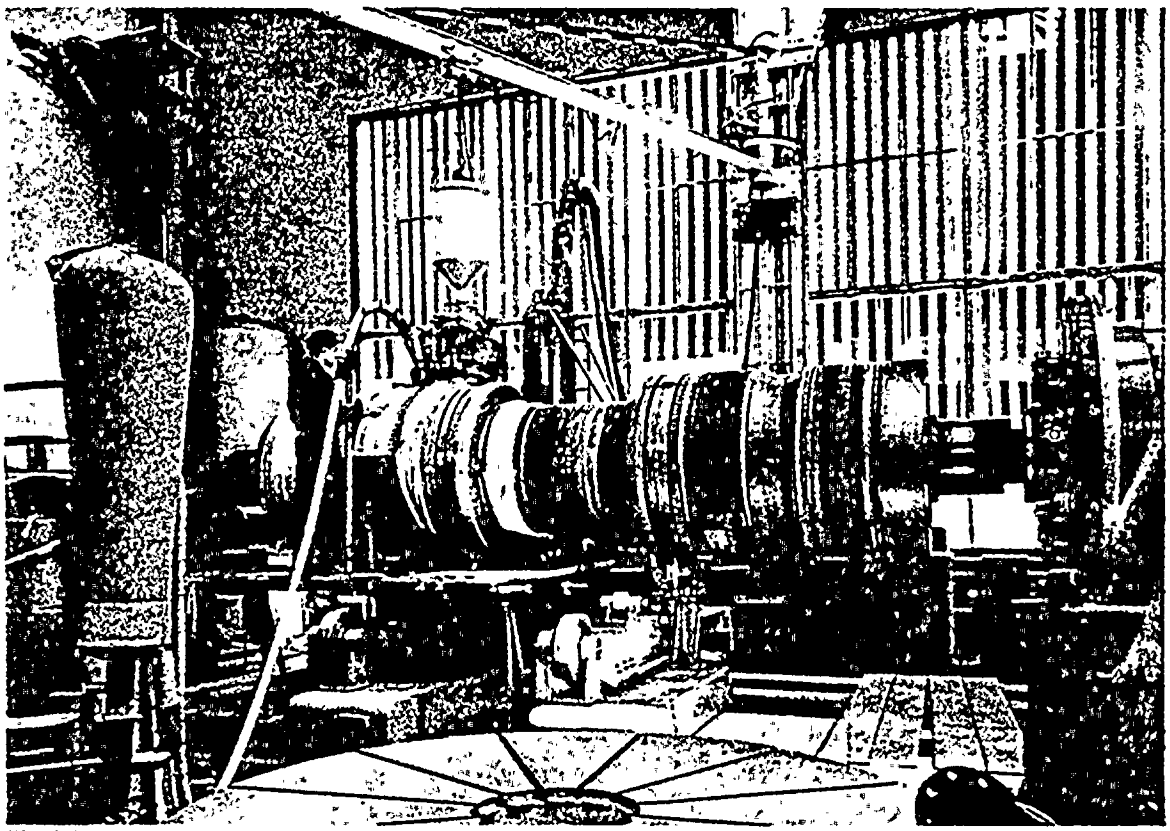


Fig. 3: Medium-sized condensing turbine rotor after machining.

Brown Boveri's rotor welding technology has been the subject of a number of articles in the technical press [4, 5]. The following is a short summary of the manufacturing procedure.
Argon arc welding is used for the root weld. Fig. 5 shows the assembled rotor in the vertical position. The required preheat temperature is obtained using induction heating.

After welding the root, filling is carried out on a horizontal lathe using submerged arc welding. Fig. 9 gives an impression of this stage of the welding process and shows the equipment for preheating and maintaining the temperature of the rotor.
Automatic methods have been used for the two welding processes – the argon arc root weld and the submerged arc filler weld – for many years and thus the same quality is achieved in all the welds of each rotor.
After welding, the complete rotor is subjected to heat treatment in an oven (Fig. 6). The surfaces close to the welds are then machined to permit ultrasonic examination of the welded zone.

Fig. 9: Completing the filler weld of a rotor on the welding lathe.



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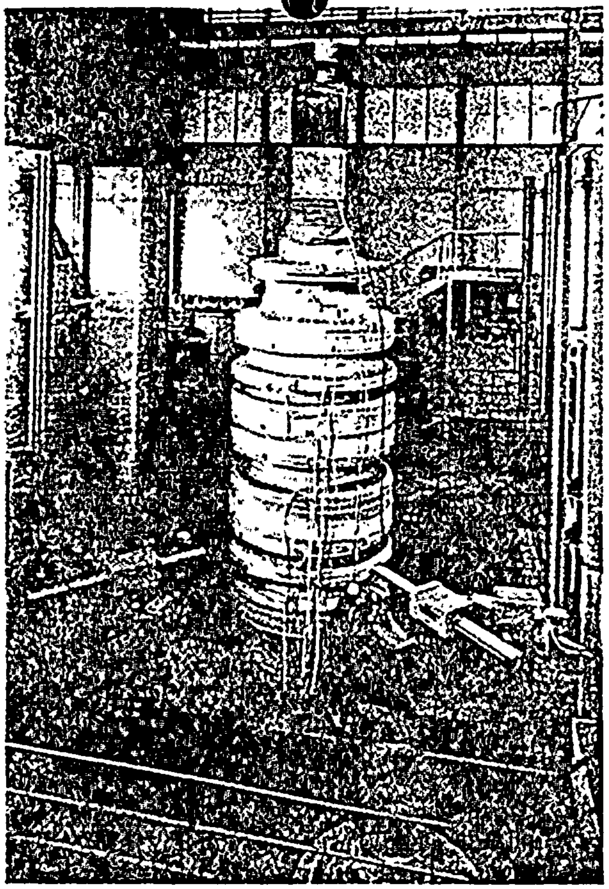

Fig. 5: Making the root weld on the 200 t low-pressure rotor of an 1100 MW nuclear turbine.

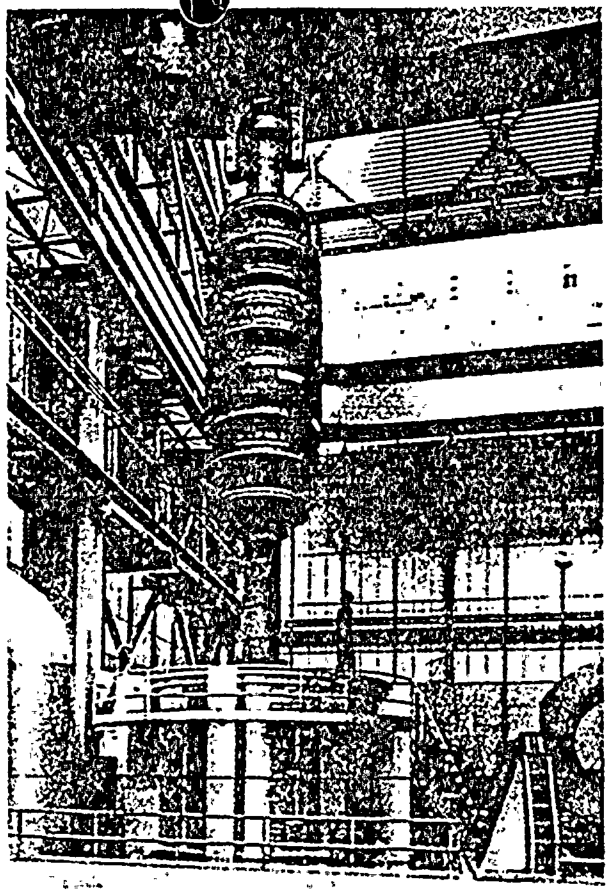

Fig. 6: Low-pressure rotor of an 1100 MW nuclear turbine after welding and stress relieving.

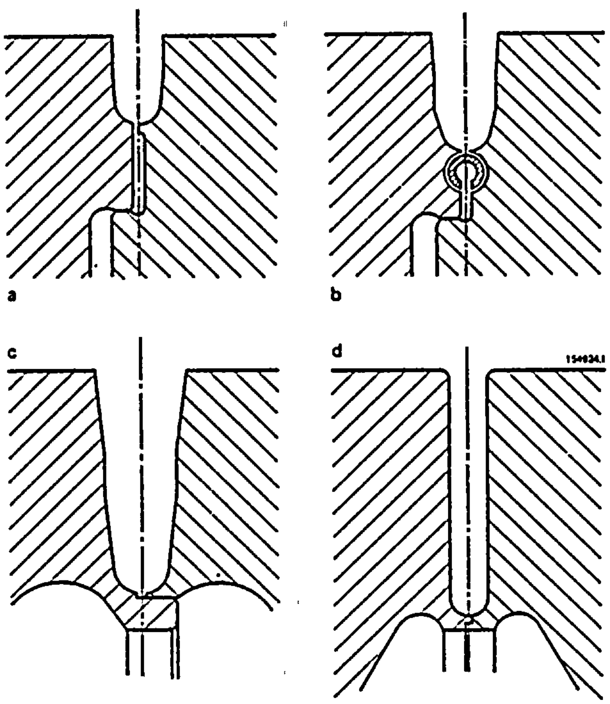

Fig. 7: BBC weld preparation shapes: development during the last 40 years.

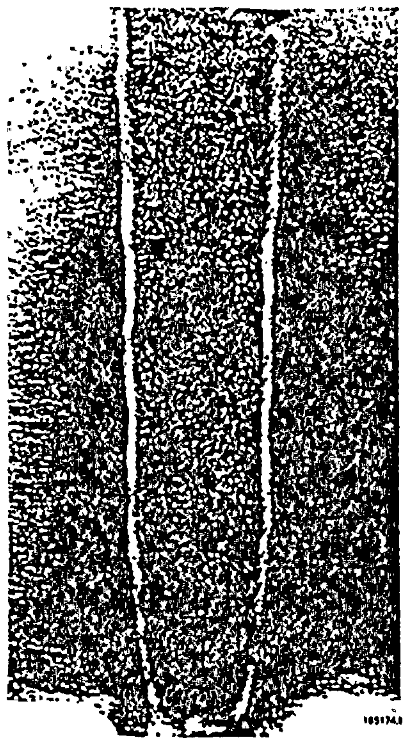

Fig. 8: Microsection of a rotor weld.

The use of modern calculation methods for the design of rotors

To design a rotor making use of the latest technologies, a large computer is used. Finite element analysis allows the operating stresses in all parts of the rotor to be accurately calculated. Fig. 10 shows the mesh used for the intermediate-pressure rotor of a 500 MW turbine to determine its isothermal field and operating stresses. For the same rotor the combined stresses due to the rotor speed and temperature (comparative stress) are shown under full load conditions in Fig. 11. All points on any line in the figure have the same comparative stress level.
Extensive information is available on the stresses in steam turbine rotors during start up. A summary of this information is given in reference [7].

Summary

Brown Boveri steam turbine rotors are designed, manufactured and inspected in such a way that a maximum of safety during operation can be guaranteed. The welded rotor has the following positive characteristics:
- exceptionally large flexural rigidity, favourable for a smooth running characteristic,
- low stress levels since the solid disks have no central bore [3],
- good quality of all highly stressed sections since the small disks can be more thoroughly forged,
- simple inspection of the individual pieces before welding and thus a high degree of safety against material defects,
- favourable heat flow during transient operation with no appreciable axial stresses at the centre of the rotor since only a two-dimensional stress pattern exists.

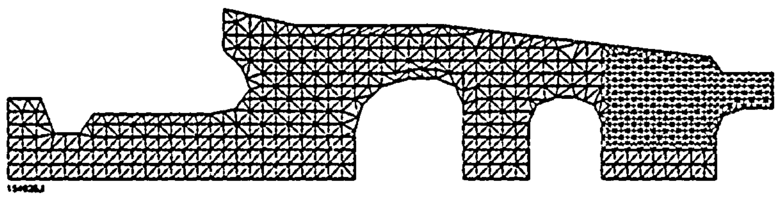

Fig. 10: The finite element mesh for the determination of the isothermal field and the operating stresses of a BBC rotor.

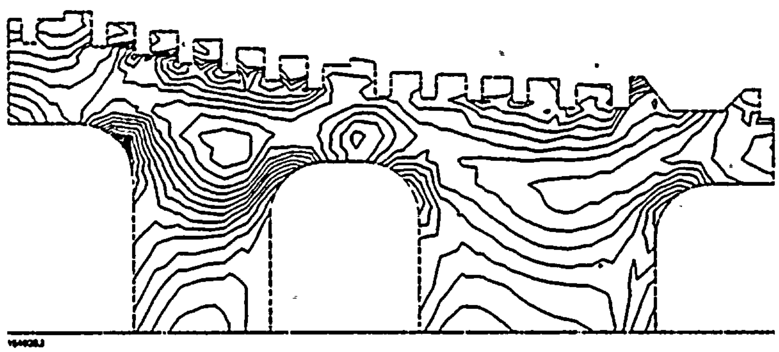

Fig. 11: Stresses in the intermediate pressure rotor of a BBC 500 MW turbine during steady-state operation.

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BBC Brown, Boveri & Company, Ltd., CH-5401 Baden/Switzerland

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