6. OPERATIONAL CHARACTERISTICS OF THE MMISG ACHIEVED AT THE BOR 60 REACTOR

6.1 Parameters at the MMISG steady state power level

In Table XI parameters are given measured in MMISG at reactor loop full load and at 66% load. The results obtained are in good agreement with the design parameters, chapter 5.

TABLE XI.
MEDIA PARAMETERS MEASURED AT THE MMISG AT BOR 60

Parameter	Dimension	66%load	Loop full load
Sodium:			
Inlet temperature	°C	414	452
Outlet temperature	°C	285	277
Flow rate	m^3/s	0.129	0.1296
Feed water:			
Inlet temperature	°C	188	199
Pressure	MPa	8.46	8.77
Superheated steam:			
Outlet temperature	°C	409	437
Mass flow rate	kg/s	8.44	11.54
Thermal power	MW	18.5	28.8

6.2 Overall heat transfer in the first period of the MMISG operation

The parameters of the MMISG were measured immediately after it was put into operation; this permitted to evaluate the real coefficient of the overall heat transfer in the

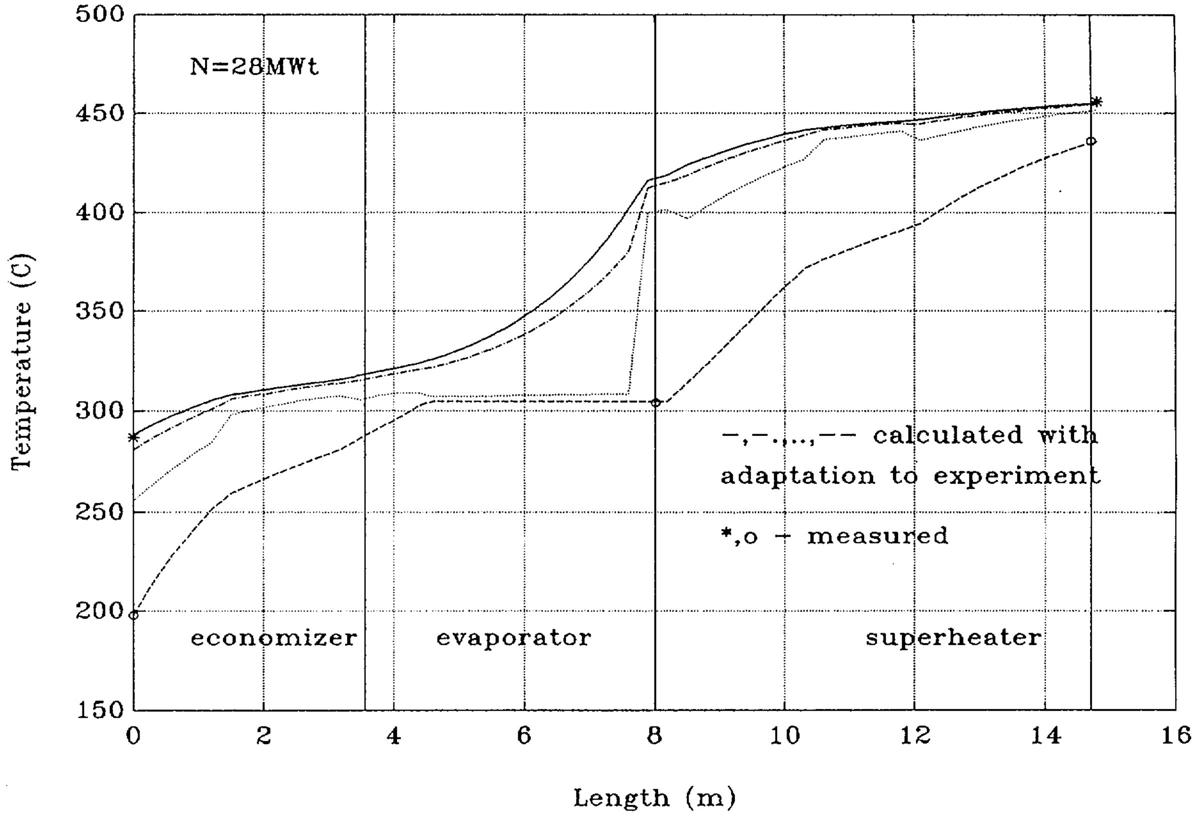

FIG.25.Sodium (——), water (- - -) and tube wall (... and _._._) temperatures along the length of the tube bundle of the MMISG

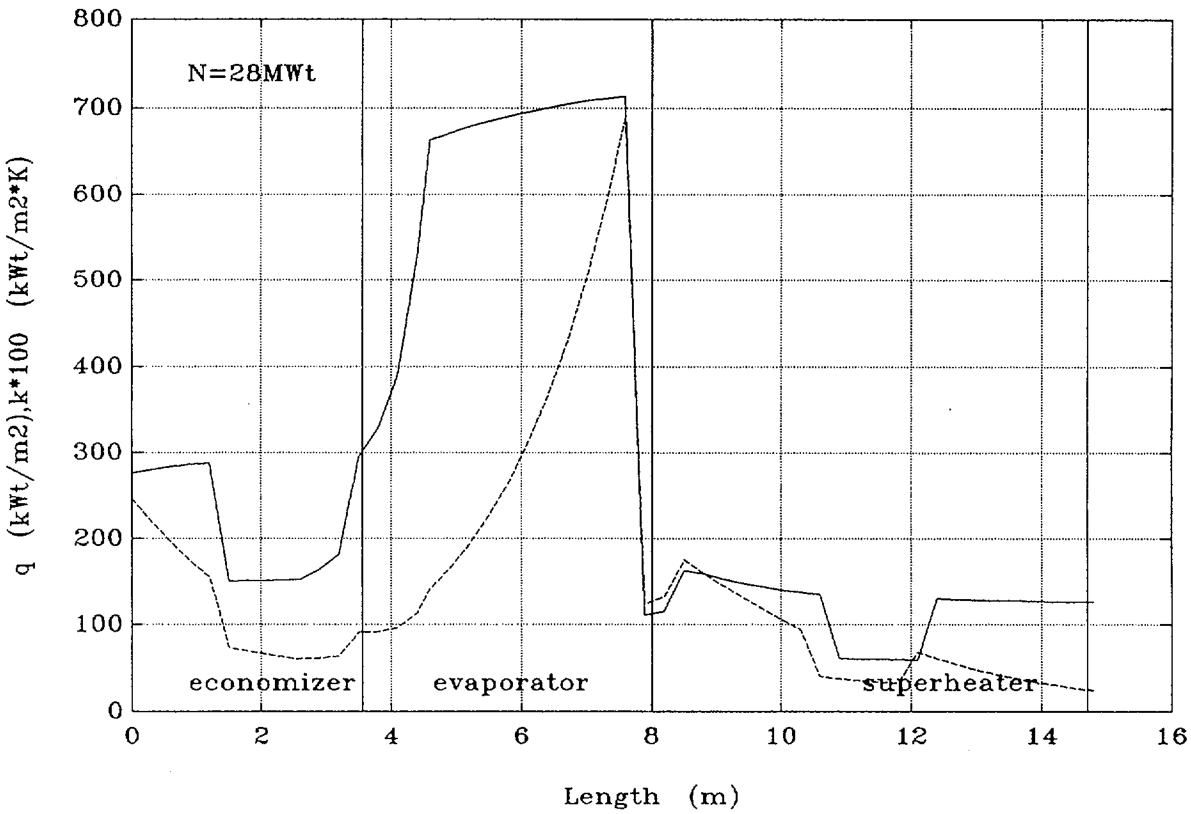

FIG.26.Distribution of heat flow rates (full line) and heat transfer coefficient values (dashed line) along the tube bundle of the MMISG

economizer, evaporator and superheater modules. The evaluation was performed by two methods:

- thermal balance for each group of modules and heat transfer surface
- step by step approximation of input data used for heat transfer calculations to the measured local temperatures.

Both methods led to satisfactory results.

Corrected and computed media temperatures for nominal thermal power are given in Figure 25. Corresponding heat transfer coefficients and heat flows are shown in Figure 26.

The difference in design and measured heat transfer coefficients of economizer and superheater modules was in the range of 10 to 15%.

The heat transfer coefficient in the evaporator modules was approximately 1.8 time higher than designed because higher thickness of deposits was considered in the design phase. The heat flow critical value was less than 690 kW/m^2.

6.3 Water and sodium flow and temperature distribution in branches

A typical distribution of sodium and water flow to MMISG branches in the condition in which the separator is connected to the MMISG is shown in Fig.27. The sodium flow rate differences in the individual branches do not exceed 5% of the mean flow value and water flow rates differences did not exceed

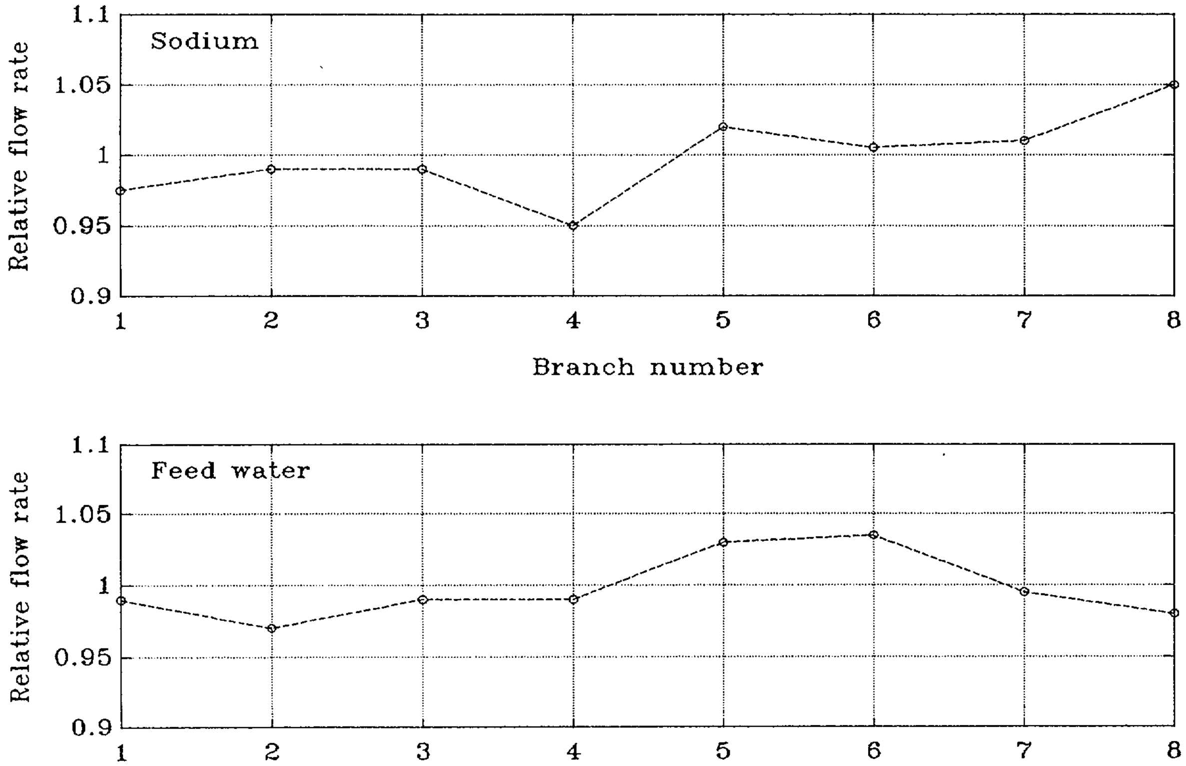

FIG.27.Distribution of sodium and water relative flow rates in branches of the MMISG with connected moisture separator

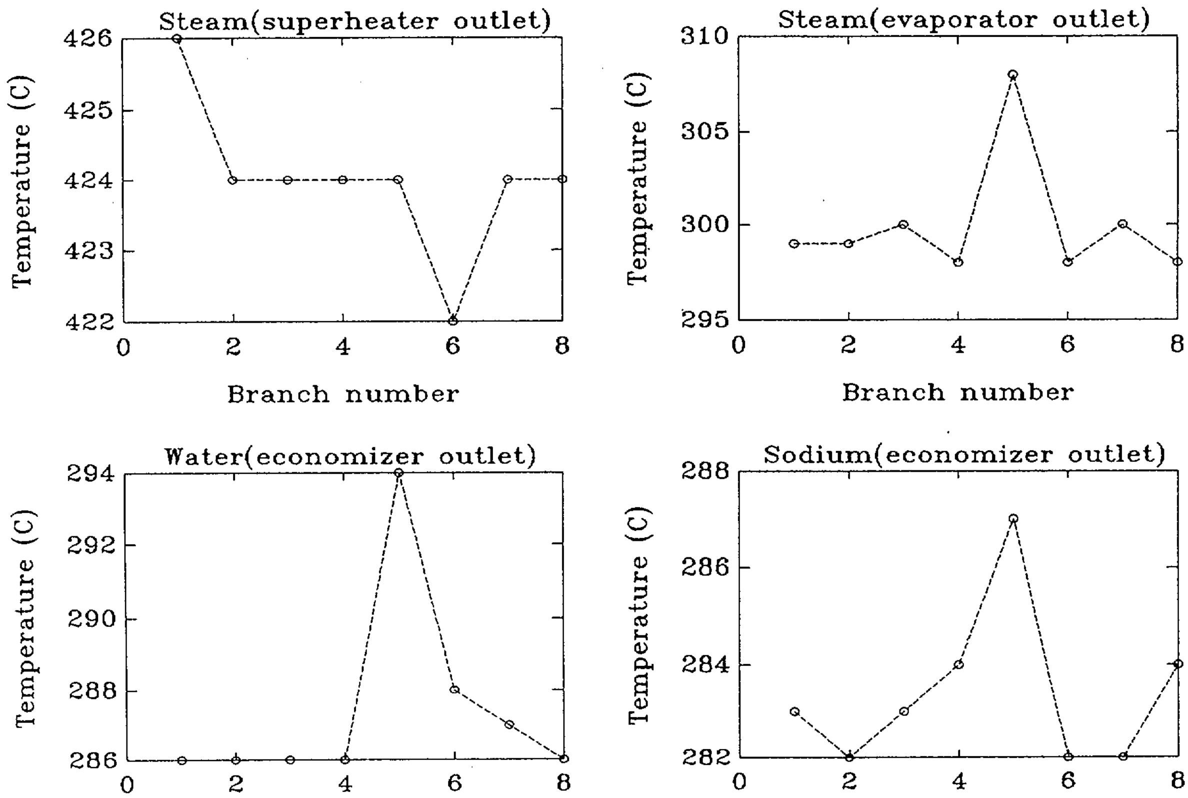

FIG.28.Differences in media temperatures at each branch of the MMISG

40% of the mean value. The measured temperatures of the media (sodium, water or steam) in the branches at identical points are practically equal in this power conditions. The differences in sodium outlet temperature of each branch are not more than 7°C and the steam temperature at the evaporator outlet modules is not higher than 15°C, Fig.28. The MMISG branches posses equal thermohydraulic characteristics which are close to those of the design [17]. The differences of media temperatures in branches increase with steam overheating in the evaporator. For example the difference of the sodium outlet temperature between the second and sixth branch ranged up to 20°C and the difference of steam temperatures at the outlet of the evaporator modules ranged up to 30°C at the steam overheating of 45 to 50°C at the same time.

A difference in the sodium temperature in tubes across the tube bundle was registred. The sodium temperature in tubes positioned at the top have been higher by 15 to 20°C than that at the bottom [18].

6.4 Hydraulic instability

One of the phenomena that have unfavourable influence on the availability of steam generators (SG) in the dynamic instability of the flow of the steam/water mixture in the evaporator. Flow control orifices (screens) were built into the inlet feed water piping of each branch. They were used for estimating the feed water flow rate changes by pressure drop measurements at flow rates of 10-50% of the nominal flow rate, water pressures of 6 and 9 MPa, and different SG conditions with separator [17,18].

Small flow rate oscillations were observed only in the startup period at low feed water flow rates; these oscillations were rapidly damped. The water flow fluctuations in the branches did not surpass 4% of the nominal flow rate. Statistical analysis of the signals from differential manometers connected to the orifices did not detect any significant correlation between the flow disturbances in the different branches. Only small conspicuous components of power spectra were observed at frequencies of 1.5-2 Hz. These components originated from the SG feed water system. At a frequency of about 0.2 Hz, components of power spectra were observed at approximately 10% of the nominal flow rate when boiling started in the evaporator. It was shown by measurements that the steam/water flow was stable in all operational conditions in the MMISG power range from 20% to 100%.

6.5 Heating of the MMISG

The heating of the MMISG is carried out step by step. The temperature increase up to 50°C in each step was selected as an input into the heating control system. As soon as the new level of temperature is achieved the feeding of heaters is controled in such a way that the new level of temperature is kept during next three hours with the aim to equalize the temperatures of the MMISG structures.

The maximal difference of 50°C was registred between the tube plate temperature and the outer water pipings temperature at the end of the economizer modules. The

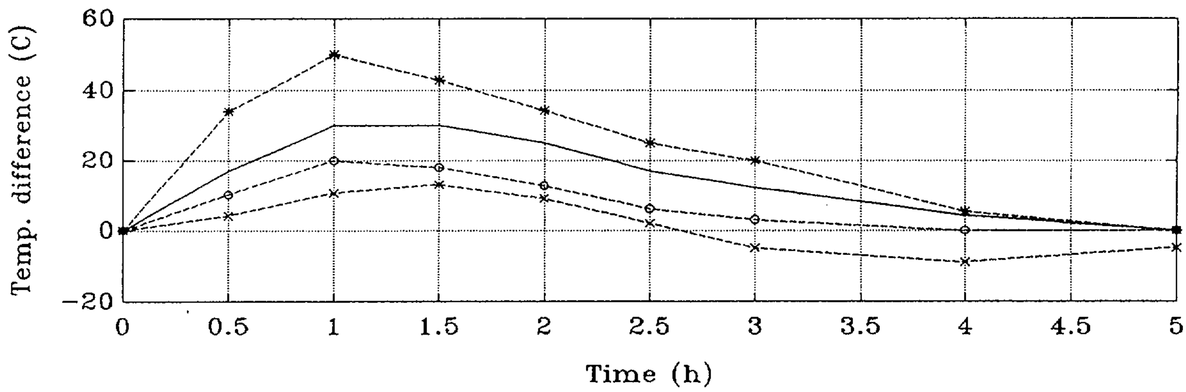

FIG.29.Maximum temperature differencies in the MMISG structure registered during one heating step
(o – between central and peripheral structure parts,
x – between upper and lower structure parts in box,
* – between steam outlet pipings and module shell tubes,
—— – calculated between heat transferring tube and module shell tube)

temperature in the high of the MMISG structure differs up to 10°C and in the width up to 20°C. Chosen results of the MMISG heating are given in Fig. 29. The heating of the MMISG structure up to 250°C takes approximately 24 hours.

6.6 Properties of structural materials after 27 000 hours of operation

One of the eight MMISG branches was cut out after 27000 operational hours of steam generating condition for turbogenerator drive to analyse properties of used materials [14]. The most frequent inlet temperature of sodium was from 450 to 460°C, sodium outlet temperature from 285 to 290°C at the sodium volume flow rate of 500 to 520 m^3/h (i.e. the mean sodium flow velocity inside the tubes of 3.2 m/s) and feed water temperature from 200 to 210°C, temperature of the superheated steam from 420 to 430°C, pressure 7.8 to 8.2 MPa and water flow mass density at the economizer inlet 130 $kg/m^2.s$

till that moment. The impurities mass concentration in feed water were ranged in iron $(9 \text{ to } 20).10^{-6}$, oxygen $(5 \text{ to } 8).10^{-6}$, copper 5.10^{-6}, chlorides 5.10^{-6}, carbon monoxide $(0.4 \text{ to } 0.74).10^{-3}$ and pH 6.0 to 7.6.

Tube corrosion at the sodium side was not identified. The thickness of the corrosion oxide layer at the tube water side was determined in the superheater of $(20 \text{ to } 30).10^{-6}$ m, economizer of about 10.10^{-6} m. The corrosion rate calculated from the oxide layer was in the economizer of 0.002 to 0.003 mm/year, evaporator 0.008 mm/year and superheater of 0.007 mm/year. All these values are approximately three times lower than stated for steel used for MMISG fabrication.

The pitting corrosion was observed on tube surfaces, namely individual separated pits in the superheater of 0.06 mm in depth, in evaporator of 0.15 mm, and in economizer less than 0.07 mm.

The deposits on the tube surface were in the evaporator of an overall areal character with a thickness of 0.2 to 0.25 mm, in the economizer of a local partial character with a density of 0.18 kg/m^2, and in the superheater of a local character with a density of 0.03 to 0.04 kg/m^2.

An analysis of the tube shell microstructure documented a moderate decarbonization at both sodium and water sides and a small rise in surface layers microhardness. Intercrystallic corrosion was observed into a depth of 30.10^{-6} in the evaporator at the water side.