

Cooperation of Russian and Czech Organizations in Steam Generator R&D :

Inverted Steam Generators for Sodium Cooled Fast Reactor

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Steam generator types and design parameters

Four types of steam generators for plants with sodium cooled fast reactors were developed in cooperation of Russian (Soviet Union) organizations and Czech (Czechoslovak) organizations and manufactured in the Czech organizations and delivered to BOR 60 in the RIAR Dimitrovgrad (Micro Modular Steam Generator - MMSG, Micro Modular Inverted Steam Generator - MMISG and Modular Inverted Steam Generator - MISG) and to BN 350 (MMSG NADA I and NADA II) in the period of 1966 to 1992.

Table 1. Some design parameters of steam generators of the Czech provenience and reactor inlet/outlet sodium temperatures

Design parameters	MMSG (BOR 60)	MMISG (BOR 60)	MISG (BOR 60)	MMSG NADA I NADA II (BN350)
Thermal power, MW	30	28	26,3	200
Sodium temperature reactor outlet, °C	550	550	550	500
Sodium temperature reactor inlet, °C	340	340	340	300
Sodium temperature SG inlet, °C	565 (max)	500	505	453
Sodium temperature SG outlet, °C	320	302	309	273
Superheated steam temperature, °C	540 (max)	475	490	435
Superheated steam pressure, MPa	10	11,6	11	5
Feed water temperature, °C	215	210	210	158
Water/steam system	forced	forced	forced	natural circulation
Sodium side	shell side	in tubes (inverted)	in tubes (inverted)	shell side

Operation

MMSG 1973-1980, MMISG 1981 up to now, MISG 1991 up to now, Nada I 1980-1991, Nada 2 1982-1992

Micro Modular Inverted Steam Generator (MMISG)

Developed in cooperation of Czech and Russian organizations and manufactured by Czech companies.

MMISG has been still in operation at one of the two loops of the BOR 60 reactor facility since September 1981 with no water into sodium leak and approx.170 000 hours of operation in the preheated steam generating mode.

Micro Modular Inverted Steam Generator (MMISG)

MMISG design features:

- 8 branches parallel connected to the inlet and outlet sodium chambers,
- SIGMA shaped branch,
- each branch consists of 3 modules (economiser, evaporator and superheater modules),
- module - shell tube O.D. of 194 mm and tube bundle of 19 tubes,
- once - through design at the water/steam side,
- sodium in tubes concept – a basis of the inherent steam generator safety if a water/steam leak into sodium should occur,
- thermal power of 28 MW (for BOR 60 application).

Modular Inverted Steam Generator (MISG)

MISG was technologically developed and manufactured by companies from the Czech Republic. MISG has been still in operation at one of the two loops of the BOR 60 reactor facility since March 1991 with no water into sodium leak and approx.135 000 hours of operation in the preheated steam generating mode.

Modular Inverted Steam Generator (MISG)

MISG design features:

- one module SG design,
- banana shaped vertical oriented module,
- module - shell tube O.D. of 521 mm and tube bundle of 246 tubes,
- once - through design at the water/steam side,
- sodium in tubes concept – a basis of the SG inherent safety,
- thermal power of 26,3 MW (for BOR 60 application).

INVERTED STEAM GENERATOR SAFETY BENEFITS

There are some specific design feature of an inverted steam generator that positively contribute to its inherent safety, namely:

Overpressure at the outer surface of tubes in the ISG mitigates or eliminates potential crack growth in the tube walls.

INVERTED STEAM GENERATOR SAFETY BENEFITS

There are some specific design feature of an inverted steam generator that positively contribute to its inherent safety, namely:

Cross section of the one tube at the sodium side in the ISG is considerably smaller than the cross section at the shell side with sodium of the traditional steam generator. Consequently, in case of even small water into sodium leak flow regime of displacement can start, it means that the liquid sodium does not flow in the leaked tube and this tube is filled by the gas and no wastage of the target tube wall to the leak location can occur.

INVERTED STEAM GENERATOR SAFETY BENEFITS

There are some specific design feature of an inverted steam generator that positively contribute to its inherent safety, namely:

Crystallization of products of the water - sodium reaction, namely of NaOH, on the tube wall at the temperatures below 350 °C is a phenomenon that can lead to a self blockade of the sodium flow into the tube with leaked wall.

INVERTED STEAM GENERATOR SAFETY BENEFITS

There are some specific design feature of an inverted steam generator that positively contribute to its inherent safety, namely:

Many parallel channels (parallel tubes in the tube bundle) to the leaked tube at the sodium side in the ISG module are available and only a redistribution of sodium flow inside the tubes of module bundle is a consequence of many of water into sodium situations.

INVERTED STEAM GENERATOR SAFETY BENEFITS

All these above mentioned items that have an inherent safety character are reasons, why there are substantial positive safety differences in an ISG in comparison to a traditional SG design in water into sodium leak situations.

INDUSTRIAL DEVELOPMENT OF MATERIAL AND TECHNOLOGY FOR STEAM GENERATOR COMPONENTS IN THE CZECH REPUBLIC

Development of material and technology for SFR steam generator components was performed in the framework of research and development project of the same name initiated by ENERGOVYZKUM and supported by the Ministry of Industry and Trade. The production of the steel of the type CrMoNb with very high purity (B factor smaller than 8) and forging, heat treatment, welding and machining technologies were verified in the Czech Republic industrial conditions in years 2003 and 2004. Manufacturing of tubes of 10mm, 20 mm and 22 mm O.D. (heat exchanging tubes for liquid sodium heated steam generators) was verified in industrial conditions too.

CONCLUSIONS

Two inverted steam generators of the Czech industry provenance have still been in successful operation with no water into sodium leaks at BOR 60 (RIAR Dimitrovgrad, Russian Federation). Micromodular inverted steam generator (MMISG) since 1981 and modular inverted steam generator (MISG) since 1991.

CONCLUSIONS

Development of material and technology for sodium heated steam generators components reflecting contemporary domestic industrial conditions in the Czech Republic was restarted in the years 2003 to 2004 and supported in the years 2008 to 2011 by the European CP ESFR project and by the Ministry of Industry and Trade of the Czech Republic.

CONCLUSIONS

We believe that the modular inverted steam generator (MISG) is an excellent candidate for application in the MBIR project.



Thank you for your attention.