VACUUM AND BAKEOUT TEST BENCHES FOR THE HESR AT FAIR

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Abstract

The Forschungszentrum Jülich, Institute for Nuclear Physics, IKP-4 has taken the leadership of a consortium being responsible for the design of the High-Energy Storage Ring (HESR) going to be part of the FAIR project on the GSI campus in Darmstadt in Germany. The HESR is designed for antiprotons but will be used for heavy ion experiments as well. Therefore the vacuum is expected to be 1 x 10^{-11} mbar or better. To achieve this also in the curved sections where 44 bent dipole magnets with a length of around 4.4 m will be installed, NEG coated dipole chambers will be used to reach the needed pumping speed and capacity. For activation of the NEG-material a bakeout system is required.

Two test benches were installed to investigate the required equipment needed to reach this low pressure:
To examine the influence of different types and quantities of vacuum pumps for the straight sections of the HESR a **vacuum** test bench was used.

And for checking the achievable end pressure and developing the bakeout system for the NEG coated dipole chambers in the curved sections of the HESR a **bakeout** test bench was used.

The results of the vacuum and the bakeout tests are presented. In addition the special design of the heater jackets inside the dipoles and quadrupoles, where the geometrical parameters are highly critical and space is very limited, is shown.

DESIGN DATA OF THE VACUUM SYSTEM OF THE HESR

The High-Energy Storage Ring (HESR) for antiprotons and heavy ions will have a circumference of approx. 575 m and will therefore be the second largest accelerator ring in the FAIR facility. The low-loss, undisturbed acceleration, deceleration, and storage of the antiprotons and heavy ions in the synchrotron is only possible under UHV conditions at an average residual gas pressure below 1 x 10^{-10} mbar, or preferably 1 x 10^{-12} mbar for heavy ions, and at a very low magnetic permeability of the vacuum components.

The required operating pressure can only be reached if all vacuum components are manufactured in accordance with the dedicated specifications for the UHV system. As a result, special requirements apply to the materials used and their processing.

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In detail the HESR will consist of 22 vacuum sections (incl. 2 for E-Cooler, 1 for PANDA), all separated with all-metal slide valves (max. section length 45 m). In the two arcs a bakeout system and a pumping system including NEG coated chambers inside the dipoles will be installed.

For roughing at least 6 mobile pumping stations with oil-free fore pumps are foreseen.

Every section contains at least two pirani and two penning test points and one mass spectroscopy.

The design data of the HESR are listed below in Table 1.

Table 1: Design Data of the HESR@FAIR

Feature	Value /Description
circumference	575 m
radius arc	r = 49,5 m
length straights	l = 132 m
No. dipoles	44 (l = 4.2 m), 50 Tm
No. quadrupoles	84 (l = 0.6 m)
No. sextupoles	60 (l = 0.3 m)
experiments	SPARC, PANDA, …
cooling systems	electron cooling 2-4 resp. 8 MeV stochastic cooling 2-4 resp. 6 GHz
dipole chambers	bended with radius of 29.43 m, 8.18°, length 4.40 m, NEG coated
spec. vacuum chambers	2 for inj. kicker, 7 for stoch. cooling, …
av. pressure range	1 x 10^{-9} … 1 x 10^{-12} mbar at RT
beam pipe	DN93x2 mm, AISI 316LN with low hydrogen content and low permeability, electropolished
No. pumping bodies	approx. 180, four ports each, with rf-mesh inside
No. pumping station roughing	approx. 6 – 8, mobile design
No. vacuum pumps	approx. 540 (IZ, TSP and NEG)
No. slide valves	22 (24), all metal with rf-mesh
No. high speed shutter	4

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VACUUM AND BAKEOUT CONCEPT OF THE HESR

In the curved sections 44 bent dipole magnets with a length of around 4.4 m will be installed. NEG coated dipole chambers will be used to reach the needed pumping speed and capacity (see Figure 1).

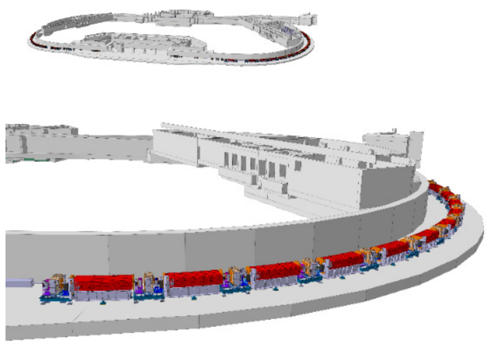

Figure 1: Layout of HESR (High Energy Storage Ring).

For activation of the NEG-material a bakeout system must be installed.

The pumping concept for the straight sections of the HESR provides a major quantity of pumping bodies which allows the installation of an optimal combination of vacuum pumps.

Two test benches were developed and built to investigate the required equipment needed to reach the required low pressure:

-to investigate the influence of different types and quantites of vacuum pumps for the straight sections of the HESR a **vacuum test bench** (see Figure 2) was used

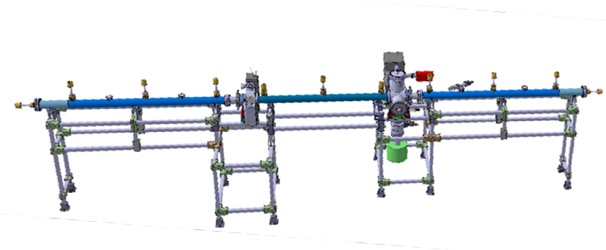

Figure 2: Layout of the vacuum test bench.

-for checking the achievable end pressure and developing the bakeout system for the NEG coated dipole chambers in the curved sections of the HESR a **bakeout test bench** (see Figure 3) was used

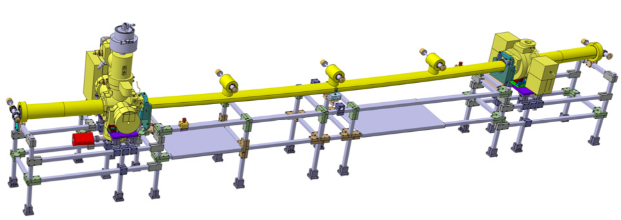

Figure 3: Layout of the bakeout test bench.

The results of the tests and the optimization of the heater jackets based on these results are presented below.

Different pumping concepts and various conditions were simulated on the vacuum test bench to optimize the combination of pumps regarding capacity, pumping speed and cost.

As an optimized version Phase 3 turned out. The small pumping cross was equipped with one Agilent ion getter pump 55 l/s and one SAES D1000 NEG pump, the big pumping cross with one Agilent ion getter pump 300 l/s and one SAES D3500 NEG pump.

	pumping cross small				pumping cross big			
Pump / Phase	IZ 55 (1)	IZ 55 (2)	NEG D1000 (1)	NEG D1000 (2)	IZ 300	NEG D3500	TSP	Reached total pressure
Phase 5	☑	☑	☑	☑	☑	☑	☑	190h. after the start - 1,25E-10mbar
Phase 6	☐	☐	☑	☐	☑	☑	☐	200h. after the start - 8,2E-10mbar
Phase 3 repetition	☑	☐	☑	☐	☑	☑	☐	205h. after the start - 5,4E-10mbar

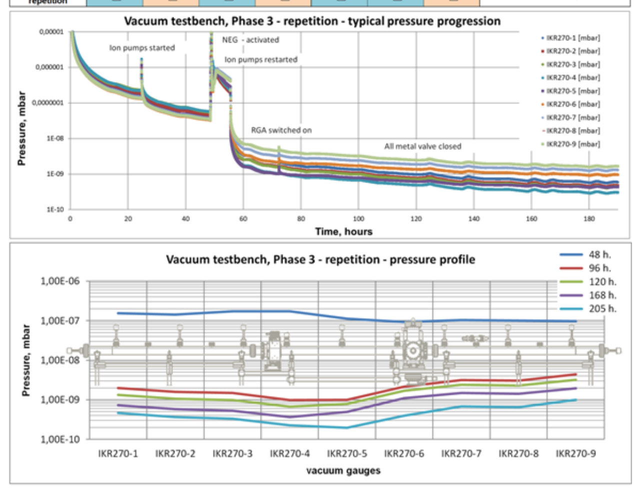

Figure 4: Vacuum test bench pressure progression and profile Phase 3.

The results of the measurement of the pressure progression and pressure profile for Phase 3 are shown in Figure 4. After 96 hours pumping a pressure of $5*10^{-9}$ mbar, after 205 hours pumping a pressure of $5*10^{-10}$ mbar at least was reached, which seems acceptable and saves an important amount of investment cost compared to a fully equipped version (Phase 5). The pressure profile shows as expected the lowest pressure between the two pumping crosses while the pressure increased by nearly one decade towards the ends of the tested tube.

Looking more into details of the available space for the heater jackets it is obvious that in many cases a special design of the heater jackets is required. Examples are the limited space inside the dipoles and inside the quadrupoles where the gap between the beam pipe and the magnet iron is only 3,5 mm (see Figure 5).

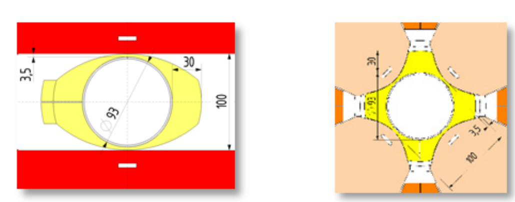

Figure 5: Limited space inside the dipoles and quadrupoles.

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The maximum temperature for the dipole and quadrupole iron is limited to 80°C and the minimum activation temperature for the NEG-coating inside the dipole chamber is 180°C. To meet both demands a special layout of the heater jackets was developed and tested on the bakeout test bench (see Figure 6).

Figure 6: Special design of the dipole and quadrupole heater jackets.

The heater jackets have two (respectively four) small areas at the top and at the bottom with only 3 mm insulation where no space is left for a heater wiring. At the sides the heater wires are placed as near as possible to these areas to accumulate as much heating capacity there as possible. The insulation thickness is up to 30mm at the sides. The outer shape of the heater jackets has been optimized to an oval design for the dipole respectively four rounded recesses due to the fact that the thermal losses increase when the surface of the jacket has direct contact to the iron of the magnet. In case of the dipole the heater wiring and the thermocouple have been installed redundant (2 heater circuits and 2 thermo couples per jacket) to avoid the lifting of the heavy (13 t) upper yoke in case of a failure.

Figure 7 shows some results of the temperature mea-surements at the testbench.for the dipole heater jackets.

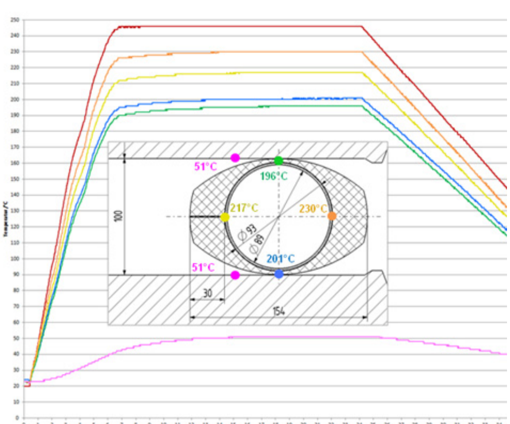

Figure 7: Temperature distribution in the dipole cross section.

The set temperature for the heater jackets was 250°C. The effective temperatures on the surface of the dipole chamber were 230°C respectively 217°C (caused by heat losses at the disconnection point) on the sides where a thicker insulation could be realised. At the top and at the bottom the effective temperatures dropped to 201°C respectively 196°C due to the thinner insulation and heat losses to the magnet iron.

Figure 8 shows the results for the quadrupole heater jackets at a set temperature of 300°C. Noticeable are the big temperature differences between maximum 294°C and minimum 150°C measured at the beam tube surface. The high temperatures are reached where sufficient space for the heater wires exists. At the areas where only 3 mm insulating material is implemented the temperature drops by nearly 90 °C in the lower and even by nearly 150 °C in the upper region due to lack of heater capacity. The reason for the higher temperature drop down is the limited space at the junction of the heater jacket resulting in a reduced number of heater wires and subsequent reduced surface temperature of 157 °C.

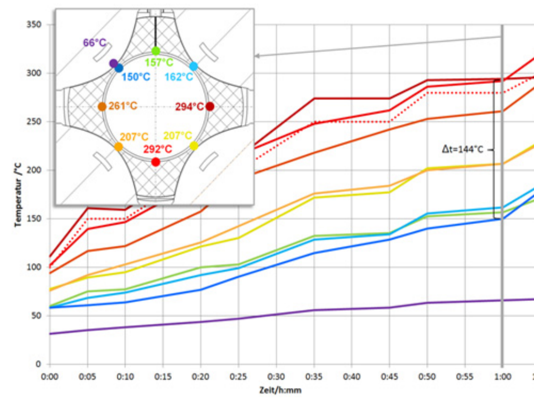

Figure 8: Temperature distribution in the quadrupole cross section.

The measured temperatures of the dipole iron was 51°C and 66°C for the quadrupole iron. The measured temperatures correlate with the in advance simulated temperatures very close and the maximum temperatures have a safe distance to the maximum allowed temperature for the dipole and quadrupole iron.

CONCLUSION

The vacuum test bench was used to optimize the combination of pumps regarding capacity, pumping speed and cost. An optimized version showed sufficient performance with a reduced equipment of pumps and offers a big potential to save investment cost.

Considering the available space for the heater jackets in many cases a special design of the heater jackets is required. Especially for the heater jackets inside the dipole and quadrupole magnets a special design had to be developed. The temperature distribution of the optimized heater jackets has been measured at a bakeout test bench to prove that the maximum temperature for the dipole iron will not be exceeded and the minimum activation temperature for the NEG-coating will be reached even in the worst case.

The optimized heater jacket design guarantees a clear distance to the maximum allowed temperature of the dipole and quadrupole iron.

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