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NEG COATED VACUUM CHAMBERS AND BAKE-OUT-CONCEPT FOR THE HESR AT FAIR

H. Jagdfeld[1]*, J. Böker², N. Bongers², P. Chaumet[1], F. M. Esser[1], F. Jordan[1], F. Klehr[1], G. Langenberg², A. Mauel[1], G. Natour[1], U. Pabst[1], D. Prasuhn², L. Semke[1], R. Tölle²

[1] Central Institute of Engineering, Electronics and Analytics - Engineering and Technology ZEA-1,
[2] Institute for Nuclear Physics IKP-4, Forschungszentrum Jülich GmbH, Germany

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 $1 \cdot 10^{-9}$ mbar with the option to achieve $1 \cdot 10^{-11}$ mbar or better. To realize 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 bake-out system is required.

To examine the influence of different types and quantities of vacuum pumps and for checking the achievable end pressure and developing the bake-out system for the NEG coated dipole chambers in the curved sections of the HESR a bake-out test bench was used.

The results of the vacuum and the bake-out 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 $1 \cdot 10^{-9}$ mbar at the worst position in the first step but with option to reach $1 \cdot 10^{-11}$ mbar or better for heavy ions later.

In detail the HESR will consist of 22 vacuum sections all separated with all-metal slide valves (max. section length 45 m).

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).

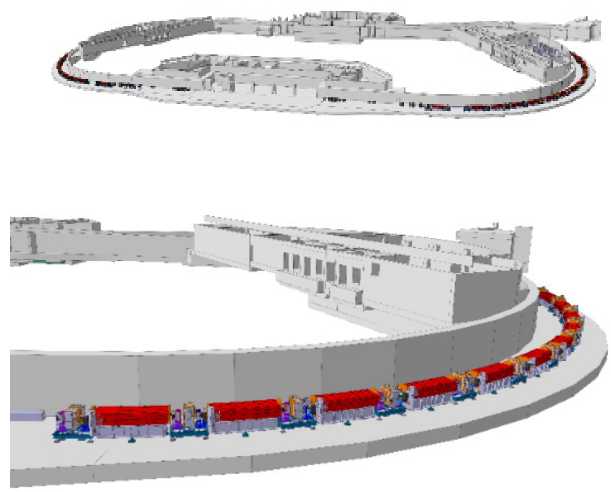

Figure 1: Layout of HESR (High Energy Storage Ring).

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

Bake-out Test Bench

To determine the required pumps needed to reach the pressure lower than $1 \cdot 10^{-11}$ mbar in the HESR, two test benches were developed and operated. The first one, the vacuum test bench, which is described in WEPML029 allows to investigate the influence of different types of pumps in the straight sections of the HESR.

The second test bench, the bake-out test bench (Figure 2), was built up to determine the achievable pressure profile in the arc sections regarding the optimized pump combination as result of the vacuum tests. The test bench consists of one NEG coated dipole chamber, two half quadrupole chambers and two different pumping bodies (small/large). The aperture of the tube is Ø 89 mm with a wall thickness of 2 mm and a total length of 6800 mm.

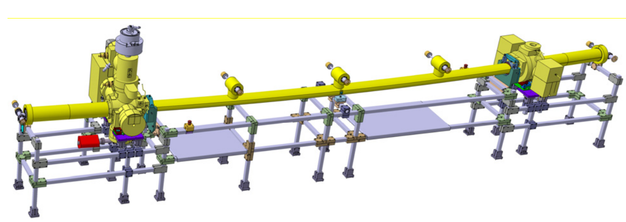

Figure 2: Layout of the bake-out test bench.

* h.jagdfeld@fz-juelich.de

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To investigate the effect of the NEG coating two test phases were performed (Table 1). The first test was executed without heating (NEG not activated) and in the second test the system is baked out for 24 hours at 250°C.

Table 1: Test Phases

Phase	Pumps					
	IZ55 #1	IZ55 #2	IZ300	D1000 #1	D1000 #2	NEG coating
(1)	x	x	x	x	x	
(2)	x		x	x	x	x

In phase 1 the end pressure reached is $1 \cdot 10^{-9}$ to $4 \cdot 10^{-9}$ mbar depending on the position of the gauge.

The combination of pumps with the lowest end pressure included the following pumps (Phase 2):

- Mobile pumping station (HiCube Classic/Pfeiffer Vacuum)
- 1 x ion pump (VacIon 55 Plus StarCell/Agilent)
- 1 x ion pump (VacIon 300 Plus StarCell/Agilent)
- 2 x NEG pump (CapaciTorr D1000/SAES)
- Activated NEG coating

The VacIon 55 and one D1000 are installed at the small pumping body. The HiCube Classic, the VacIon 300 and one D1000 are mounted on the large pumping body.

The tests with the selected pumps are divided into three steps to see the influence of the different types of pumps:

1. HiCube Classic + ion pumps (switched on after 167 h)
2. HiCube Classic + ion pumps (from the beginning)
3. HiCube Classic + ion pumps + NEG pumps

The test bench is vented with air for one day after every step.

In Figure 3 the pressure profile of phase 2 is shown. The lowest end pressure after 230 h is reached at position 12/13 and the highest end pressure at position 6/7.

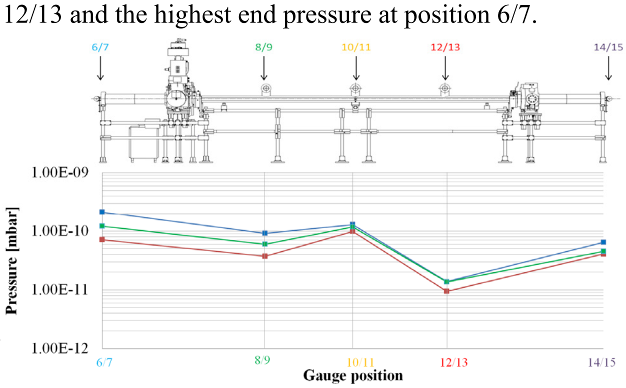

Figure 3: Pressure profile (Phase 2).

The whole pumping process for the described steps is shown in Figure 4. The diagram includes the data of the gauge positions with the highest (7) and lowest pressure (13).

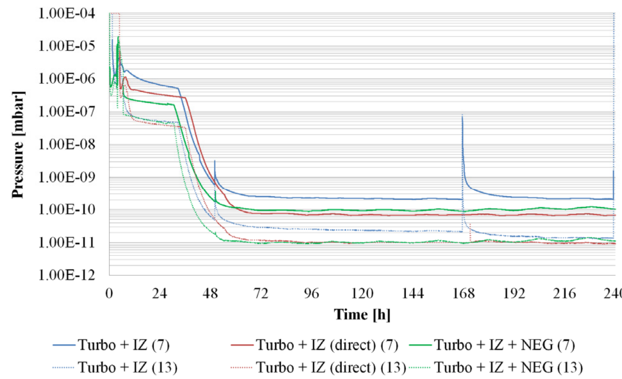

Figure 4: Pumping process (Phase 2).

Step 2 provides the lowest pressure. At position (7) it is $7 \cdot 10^{-11}$ mbar and at position (13) $9 \cdot 10^{-12}$ mbar. The effect of the NEG pumps is low compared to the effect of the activated NEG coating of the dipole chamber. For activation of the NEG coating, the arcs are equipped with heater jackets. The heating process (Figure 5) starts when the pressure of $1 \cdot 10^{-6}$ mbar is reached.

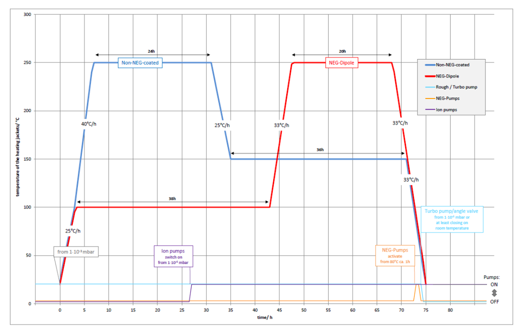

Figure 5: Heating process.

The comparison of the data of the two test benches with the same pump installation shows that the activation of the NEG coating results in lower end pressure, better pressure profile and shorter time for the pumping process.

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 6).

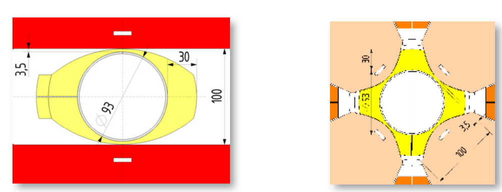

Figure 6: Limited space inside the dipoles and quadrupoles.

The maximum temperature for the dipole and quadrupole iron is limited to 80°C whereas 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 a bake-out test bench (see Figure 7).

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Figure 7: Special design of the dipole (left) and quadrupole (right) 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 30 mm 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 8 shows some results of the temperature measurements at the test bench for the dipole heater jackets.

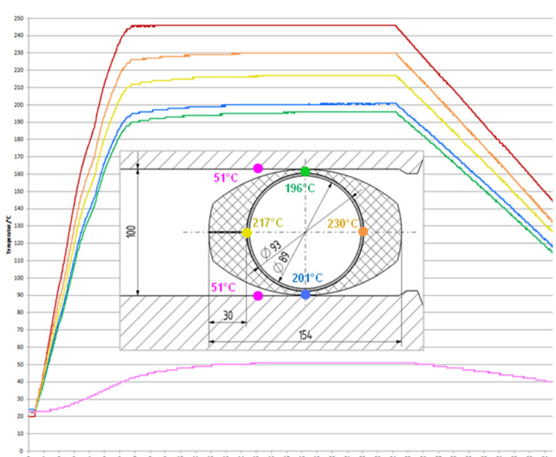

Figure 8: Temperature distribution in the dipole cross section.

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 9 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.

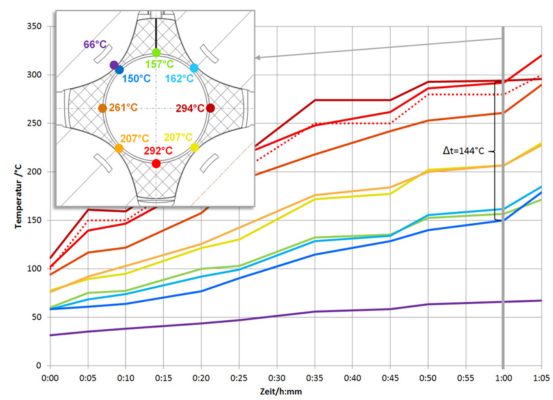

Figure 9: Temperature distribution in the quadrupole cross section.

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

NEG coated dipole chambers will be used to reach the needed pumping speed and capacity. For activation of the NEG-material a bake-out system is required.

A vacuum test bench was used to optimize the combination of pumps regarding reachable pressure, 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 bake-out 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.