Forces caused by vacuum spring bellows during pumping of the quadrupole magnet module

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Abstract. The paper is focused on effect of forces induced by vacuum bellows due to differential pressure inside and outside of the bellows. This phenomenon can develop stress into rest of the vacuum system. In case of the beam pipe in NICA booster synchrotron bellow forces developed bending moment and there is a risk of the beam pipe destruction. The problem is analysed and FEA analysis is prepared. Due to unknown bellow stiffness between beam pipe modules in FEA analysis the experimental measurement is necessary.

Introduction

Spring bellows are standard parts used in vacuum assemblies. The bellows are often used for vibration decoupling, for example, between vacuum pump and measuring instrument, they can be used as compensators to balance thermal expansion and mounting tolerances and they also can serve as feedthroughs to introduce movements into the vacuum or to separate the vacuum chamber from mechanical parts.

The paper is focused on effect of forces induced by vacuum bellows used for connecting of the beam pipe with the UHV pumping system in quadrupole magnet modules in NICA booster.

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex designed at the Joint Institute for Nuclear Research (JINR) to study properties of dense baryonic matter. The accelerator tube is assembled from similar modules connected inside a big vacuum chamber where fore vacuum helped to reach high vacuum in the beam pipe. All inner parts are at temperature of liquid nitrogen (approximately 70K). The serial assembly and testing of NICA booster magnets started at special facility of the Laboratory of High Energy Physics. It is necessary to assemble and test 48 quadrupole magnets for NICA booster synchrotron. [1]

The quadrupole magnet module design and details of the analysed beam pipe fixed in the lens are shown in the Fig. 1.

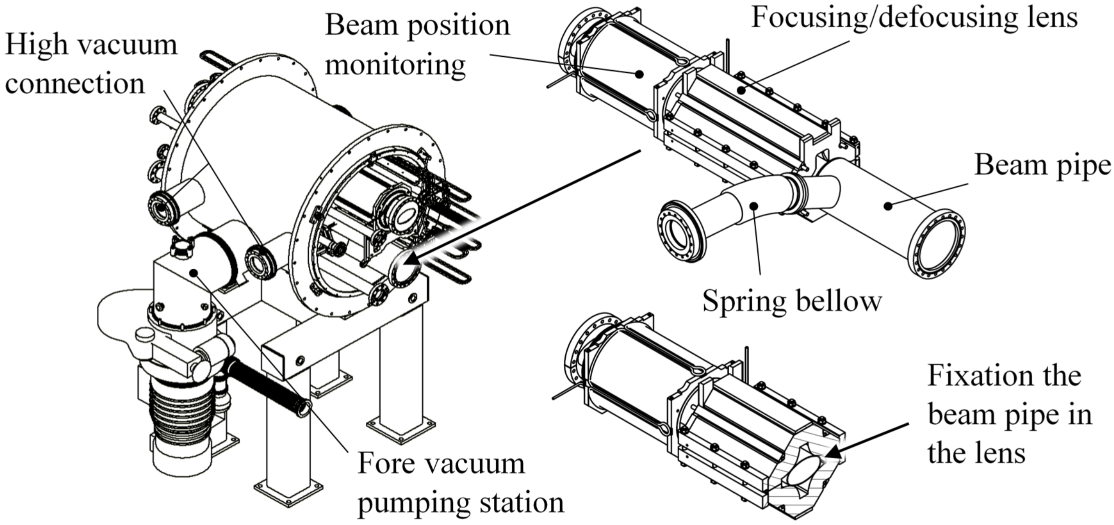

Fig. 1 - The quadrupole magnet module with the beam pipe

Because each accelerator is a source of potentially dangerous ionizing radiation it is necessary to reduce the risk of its failure. Therefore, virtual tests and real tests are applied to all components of the quadrupole magnet module mechanical structure.

Problem - spring bellow force

The important constrain of the vacuum system design is the fact, that the spring bellows are getting shorten during pumping due to presence of external overpressure. This phenomenon can cause stress into rest of the vacuum system.

We took into account two main modes of pressure load during using the quadrupole magnet module in NICA booster. Each part of the module is at the atmospheric pressure – mode 1 or all parts are under certain level of vacuum – mode 2, presented in Fig. 2. In these both cases, there is no problem caused by bellow deformation.

But during commissioning there is used another case of load a mode 3 where a high vacuum is present in the beam pipe and whereas the atmospheric pressure is in the accelerator tube. We want to prevent of extreme force rise from deformed bellow and risk of the beam pipe destruction due to developed bending moment.

To prevent destruction of the beam pipe the FEM analysis of presented load mode is prepared.

Operating mode	p_1	p_2	$F = A\Delta p$
1	p_{vac1}	p_{vac2}	*negligible*
2	p_{atm}	p_{atm}	*0*
3	p_{vac1}	p_{atm}	*critical*

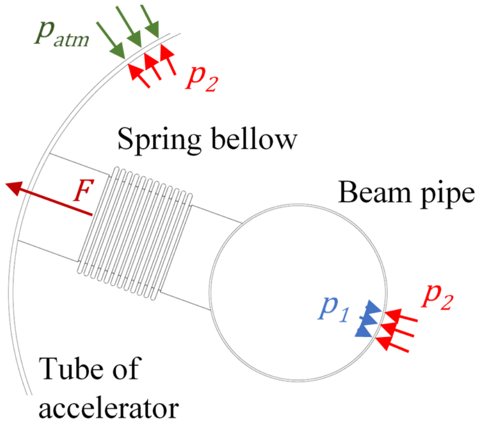

Fig. 2 – Operating modes

Virtual experiment - FEM analysis

The bellow force for the load mode 3 is evaluated from known boundary conditions (dimensions, pressures) and with help of the FEM simulation. Main outcome of calulations are deformations values and constrictions maps with clear identification of critical parts of the design. Calculations are done for two cases. The first case has free end at the site of the circular flange. The second case uses an elastic linkage at the site of the circular flange to simulate connection to another module by means of a bellow.

Used model characteristics. The problem is modeled by means of shell elements with appropriate thicknesses. Both rectangular and triangular shape of finite elements are used.

The model supports are placed on the surface lines of the elliptic tube and modeled as line supports where all the deflections are restrained and rotations are free.

For the second case, the introduced model is supplemented by an elastic linkage with defined stiffness in Z direction to illustrate the impact of connection of the particular modules (Fig. 3).

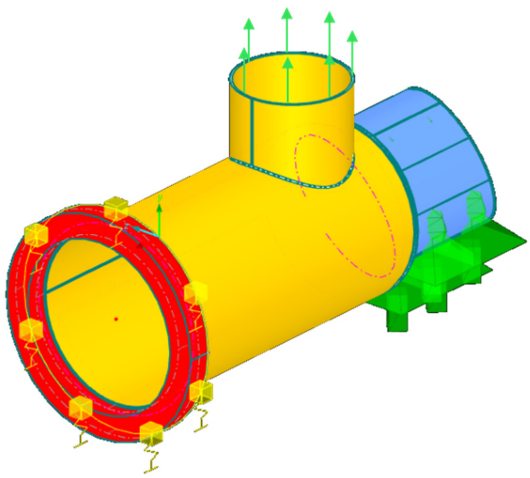

Fig. 3 - Line support with defined stiffness in Z direction

The loading force is distributed to the top circumference of the tube connecting the vacuum pump and modeled as the line load.

The computation was performed with considering geometrically linear analysis. The material is considered linear elastic with modulus of elasticity E = 190000 MPa, Poisson´s ratio ν = 0.27 and yield strength 172 MPa (not considered in computations, but used for results interpretation).

Results. FEM analysis showed the critical stress exceeds shear stress limit of the used material by more than 1.36-times for the first case with free end at the site of the circular flange (Fig. 4).

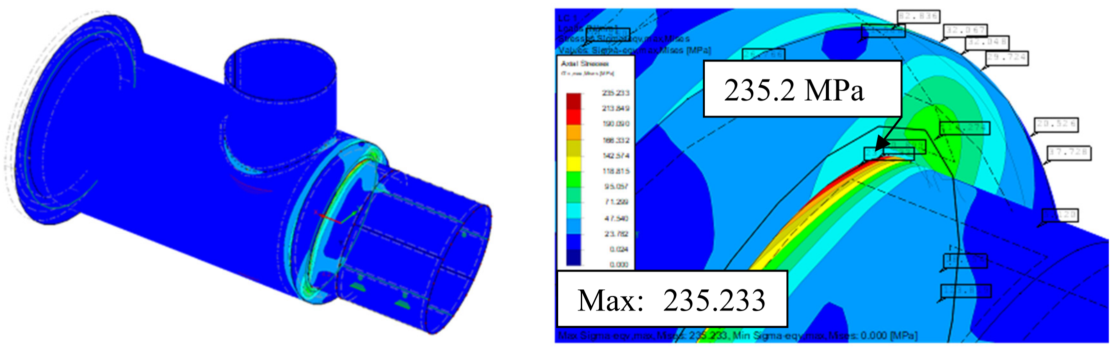

Fig. 4 - von Mises stress - 1st case

For the second case with an elastic linkage simulation indicated that all deformations can be almost neglected and maximum von Mises stress is 63.8 MPa (Fig. 5).

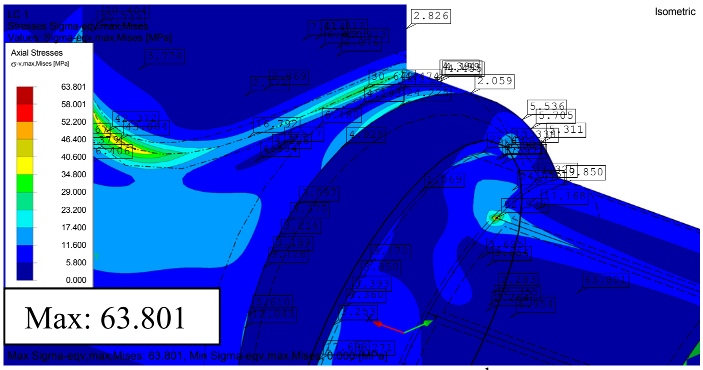

Fig. 5 - von Mises stress - 2nd case

The real stiffness of the elastic linkage used in simulation is unknow paremetr. Due to that it is neccessary to prepare a physical experiment for the result confirmation.

Real experiment

We consider a strain gauge measurement but while we are interested in behaviour just at the level of maximum load we decided to assemble the beam pipe modules together and tested its behaviour under the force effects. It is showed that all assembly totally changed its behaviour compared to a single beam pipe. Influence of connection of the individual modules seems to be crucial. The physical experiment on assembled modules showed that stiffness of comlpete assembly is high enough for safety operation in accelerator.

Decision to test behaviour of comlpete assembly confirmed correctness of the vacuum system design and enable to continue faster in production of magnet modules for NICA booster synchrotron. It confirmed the virtual FEM experiment, allowed to check the beam pipe safety under real conditions, and saved money and time.

Conclusion

FEM analysis as a tool for virtual test can significantly help during vacuum system design phase, but its results are strongly dependent on correctness of boundary conditions. In this project a simple physical experiment helped to verify the beam pipe design safety. Based on the measured data we improved the boundary conditions for next use of the vacuum system FEM model.

Acknowledgement

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References

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