# SUPERCONDUCTING RF CAVITY FOR Φ-FACTORY

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## Abstract

A single cell 700 MHz superconducting RF cavity will be employed for the Φ-Factory to be built in Novosibirsk. The cavity has a 100 kW coaxial input coupler and waveguide HOM couplers. A cavity of similar design but without input coupler is being fabricated for BEP electron storage ring. Electromagnetic fields in the cavity will be induced by electron beam.

## Introduction

A new electron-positron collider with a super high luminosity in the Φ-meson energy region (a center-of-mass energy of 1.02 GeV) called as the Φ-Factory is designed at the Institute of Nuclear Physics [1]. It is a machine with very short and intensive electron and positron bunches. Therefore the vacuum chamber of the collider must be smooth to the utmost in order not to induce beam instabilities and bunch lengthening.

RF cavities are very big discontinuities in the vacuum chamber and can cause troubles in beam dynamics if incorrectly designed. The number of them should be minimal. The cavities should also have a low broadband impedance.

Accelerating cavities are parts of the Φ-Factory RF system the purpose of which is to compensate the coherent and incoherent energy losses of the beams and to obtain a short bunch length. Each bunch (having the length $\sigma_l$ = 0.75 cm) contains $2\cdot10^{11}$ particles and circulating current is about 300 mA per bunch. The incoherent loss power will be 20 kW for one bunch mode (one electron and one positron bunch) and 60 kW for multibunch mode (three electron and three positron bunches). The coherent loss power is approximately the same. The operating frequency of the Φ-Factory RF system is taken of 700 MHz because 100 kW CW klystrons are available at this frequency. Main parameters of RF system are given in Table 1.

Table 1: RF System Parameters

| | |
|---|---|
| RF frequency $f_{rf}$ - | 700 MHz |
| Harmonic number $h$ - | 76 |
| Accelerating voltage $V$ - | 1000 kV |
| Number of RF cavities $N_c$ - | 1 |
| Cavity shunt impedance $R/Q$ - | 77.6 Ohm |
| Cavity $Q$ - | $(0.7\text{-}1)\cdot 10^9$ |
| Incoherent loss power $P_{sr}$ - | 20 / $60^*$ kW |
| Coherent loss power $P_{hom}$ - | 20 / $60^*$ kW |
| Total klystron power $P_t$ - | 40 /$120^*$ kW |
| Number of klystrons $N_k$ - | 1 / $2^*$ |

*) Parameters for the multibunch case.

## Choice of cavity design

It was decided to use a superconducting cavity in the RF system of the Φ-Factory (instead of two or even three copper cavities). This allows to reduce the RF power, number of klystrons (1 instead of 2), the coherent loss and broadband longitudinal impedance which is very important for the Φ-Factory.

The design voltage (1000 kV) can be obtained in one superconducting cavity with the accelerating gradient of 4.6 MV/m and the Q value of $(0.7\text{-}1)\cdot 10^9$. These figures are quite realistic at the up-to-date technology level.

In any cavity design we have to reduce artificially the Q values of higher order modes (HOM) in order to ensure stability of electron and positron beams. Electromagnetic fields that are induced in RF cavity by an electron or positron bunch pass should decay substantially before the next bunch pass if HOM damping is efficient. So the cavity decay time at higher order modes, $\tau = 2Q_L/\omega_r = Q_L/\pi f_r$, ($f_r = \omega_r/2\pi$ - HOM resonance frequency) should be less than (or approximately equal to) the bunch repetition period $T_o = 1/f_o$. Therefore we have a constraint for the HOM loaded $Q_L$:

$$Q_L \le \pi \frac{f_r}{f_o}$$

E.g. for the nearest azimuthally symmetric higher order mode ($f_r$ ~ 1200 MHz) and six bunches (3 electron and 3 positron bunches, $f_o \approx 60$ MHz) we have $Q_L \le 60$, for two bunches ($f_o \approx 20$ MHz) - $Q_L \le 180$.

Estimates of increments of longitudinal oscillations for the real cavity geometry (which must be less than radiation decrement) give the $Q_L$ values of 50-100 for six bunches and 500-700 for two bunches.

HOM damping is the effective if an absorber is placed directly in the beam tube joined to the cavity which is actually a part of the storage ring vacuum chamber [2]. Its diameter should be chosen so that all electromagnetic waves with frequencies of cavity HOMs could propagate along the tube but the wave with the fundamental frequency could not. Thus the waveguide works as a filter which isolates the absorber from the cavity for the fundamental mode. According to calculations the Qs of nearest higher order modes reduce to values about 20 if the absorber is ideal.

A disadvantage of this damping method is the large length of the cavity together with its absorbers. It is difficult to locate the cavity in a relatively short (approximately 1.2 m) engineering straight section of the Φ-Factory. Moreover there is also a problem of the thermal radiation emitted by absorbers into the cavity having the temperature of liquid helium.

We can clear the first obstacle by choosing an asymmetric cavity design (Fig.1) and positioning the electrical center of the cavity not in the center of the straight section but shifting it by a half of the wave length i.e. 0.214 m. There are two ways to reduce the thermal radiation power from the absorber that falls on cavity walls: i) to locate the absorber far enough from the cavity in order to diminish the fraction of radiation which can reach the cavity, ii) to cool the absorber to the temperature, e.g., of liquid nitrogen. The first way cannot be realized because the straight section is too short. The second way is unsuitable because of high power dissipation (about 10 kW). It is impossible to conduct away such power by liquid nitrogen.

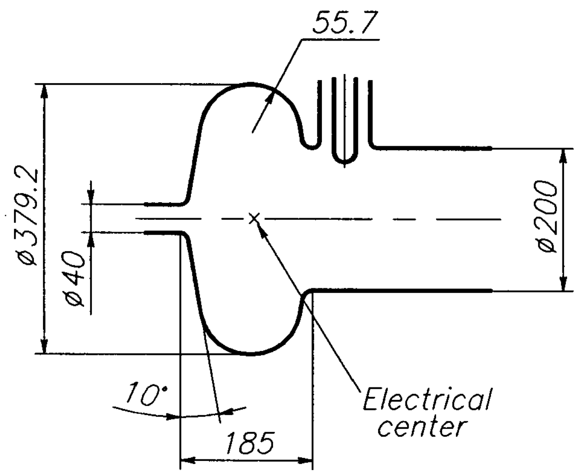

Fig. 1: *Asymmetric cavity with HOM absorber located on the wall of the expanded beam tube.*

Cavity parameters:

Shunt impedance $R/Q$ - 118.8 Ohm
Geometry factor $G$ - 231 Ohm
Peak electric field $E_p$ - 10.1 MV/m
Peak magnetic field $B_p$ - 22.8 mT

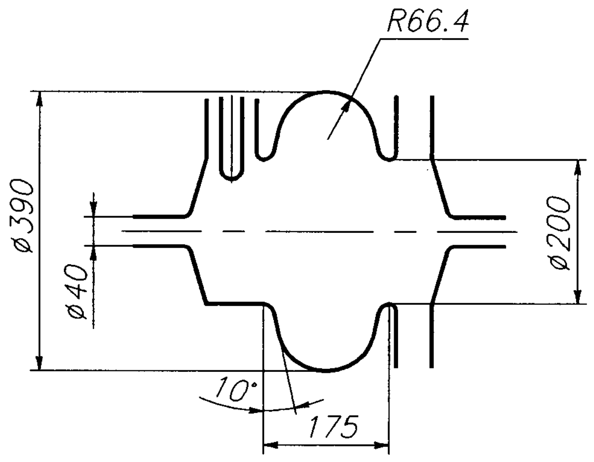

Fig. 2: *Symmetric cavity with HOM absorbers located in rectangular waveguides, with small beam tubes.*

Cavity parameters:

Shunt impedance $R/Q$ - 86.2 Ohm
Geometry factor $G$ - 265 Ohm
Peak electric field $E_p$ - 10.2 MV/m
Peak magnetic field $B_p$ - 22.8 mT

There is a cavity design which has no drawbacks mentioned above. It is possible to place the absorbers in rectangular waveguides joined to the beam tube just near the cavity (Fig.2). The beam tube aperture can be reduced after this junction to the regular size. But the damping efficiency is several times lower in this case. The number of waveguides should be not less than two for good damping of axially nonsymmetrical cavity modes. Damping of the axially symmetrical HOMs would be also better.

When choosing cavity geometry and design we must take into account the intensive synchrotron radiation from bending magnets. The direct hitting cavity walls by SR is absolutely prohibited. The distance between the magnet edge and the cavity is small, therefore the radiation angle to the beam axis is rather large (3°40’), the light deviates at 41 mm from the axis in the middle of the straight section. So it is necessary to provide special slits in the beam tubes and cavity walls for the synchrotron light to pass through to the light absorbers located in the warm area or to make the beam tube diameter large enough to let synchrotron light inside. In the first case the cavity design becomes more sophisticated, in the second case the cavity shunt impedance decreases and liquid helium consumption increases.

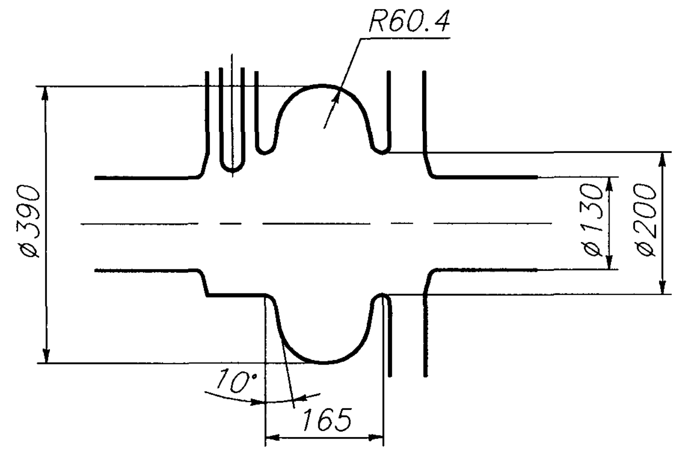

Fig.3: *Symmetric cavity with HOM absorbers located in rectangular waveguides, with large beam tubes.*

Cavity parameters:

Shunt impedance $R/Q$ - 77.6 Ohm
Geometry factor $G$ - 250 Ohm
Peak electric field $E_p$ - 12.0 MV/m
Peak magnetic field $B_p$ - 25.1 mT

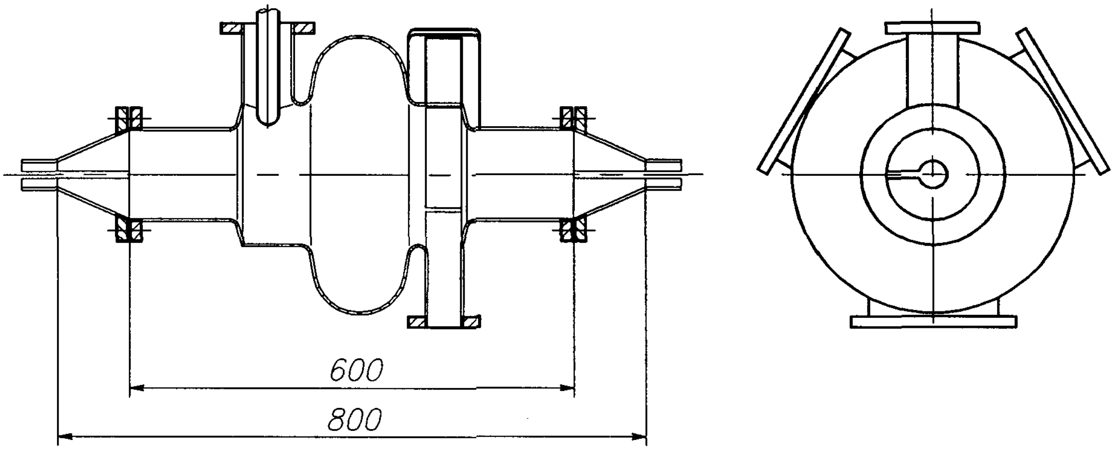

Fig.4: *Symmetric cavity with large beam tube: joining to collider vacuum chamber and waveguides disposition.*

The cavities shown in Figures 1 and 2 have small apertures and must have slits. A cavity with large aperture is shown in Figures 3 and 4. We decided to use this cavity design for the Φ-Factory.

The input coupler of the cavity has a coaxial design with an antenna tip. A ceramic RF window which isolates the cavity vacuum and air is placed in a room temperature region of the coax input line. We intend to use the window from a klystron (700 MHz, 100 kW) for this purpose. But its operation here is harder than in the klystron because of reflection of some RF power from the cavity. Therefore additional high power tests are necessary.

### The BEP cavity

Some ideas of the Φ-Factory are supposed to be tested in other machines, in particular in the BEP storage ring [3]. For instance there are plans to install a superconducting niobium RF cavity in this machine in order to compress an electron bunch to a length size of the order of 1 cm.

Such a cavity was designed (Fig.5,6). It is a passive cavity, there will be no external RF generator to drive it. Electromagnetic fields in the cavity will be induced by the electron beam passing it. The cavity has a resonance frequency of the fundamental mode near the 54th harmonic number of the storage ring revolution frequency (724 MHz). The cavity will be always out of resonance. During the injection and storage process it will be strongly tuned off. Then, if a bunch compression would be necessary the cavity will be tuned on close to the resonance (depending on the bunch current and on the compression degree). The beam induced cavity voltage is determined by

$$V = I_0 \cdot \frac{R}{Q} \cdot \frac{f_r}{2\Delta f},$$

where $I_0$ - average beam current, $\Delta f = f_h - f_r$, $f_h = h \cdot f_s$, $f_s$ - the beam revolution frequency, $h$ - harmonic number.

Cavity tuning is accomplished by its longitudinal squeezing. For beam currents of the order of 100-200 mA the tuning precision (0.3-0.5 μm) does not differ substantially from precision for normal conducting cavities. Therefore no piezo or other exotic devices are used.

The cavity geometry is not the most optimal one. It is shorter than it is necessary for the highest R/Q because there is not enough room in the straight section of the BEP storage ring. For the same reason the insulation space between helium tank and cryostat housing is joined to the inner space of the cavity (i.e. they have a common vacuum).

Two rectangular waveguides terminated with absorbing loads function as HOM dampers. Measurements on a copper model of the cavity showed $Q_L$ values for first higher order modes in the order of several hundreds.

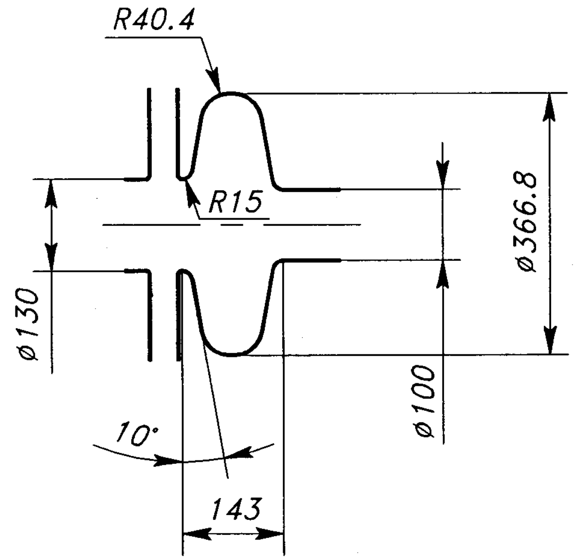

Fig.5: *Geometry of the BEP cavity*

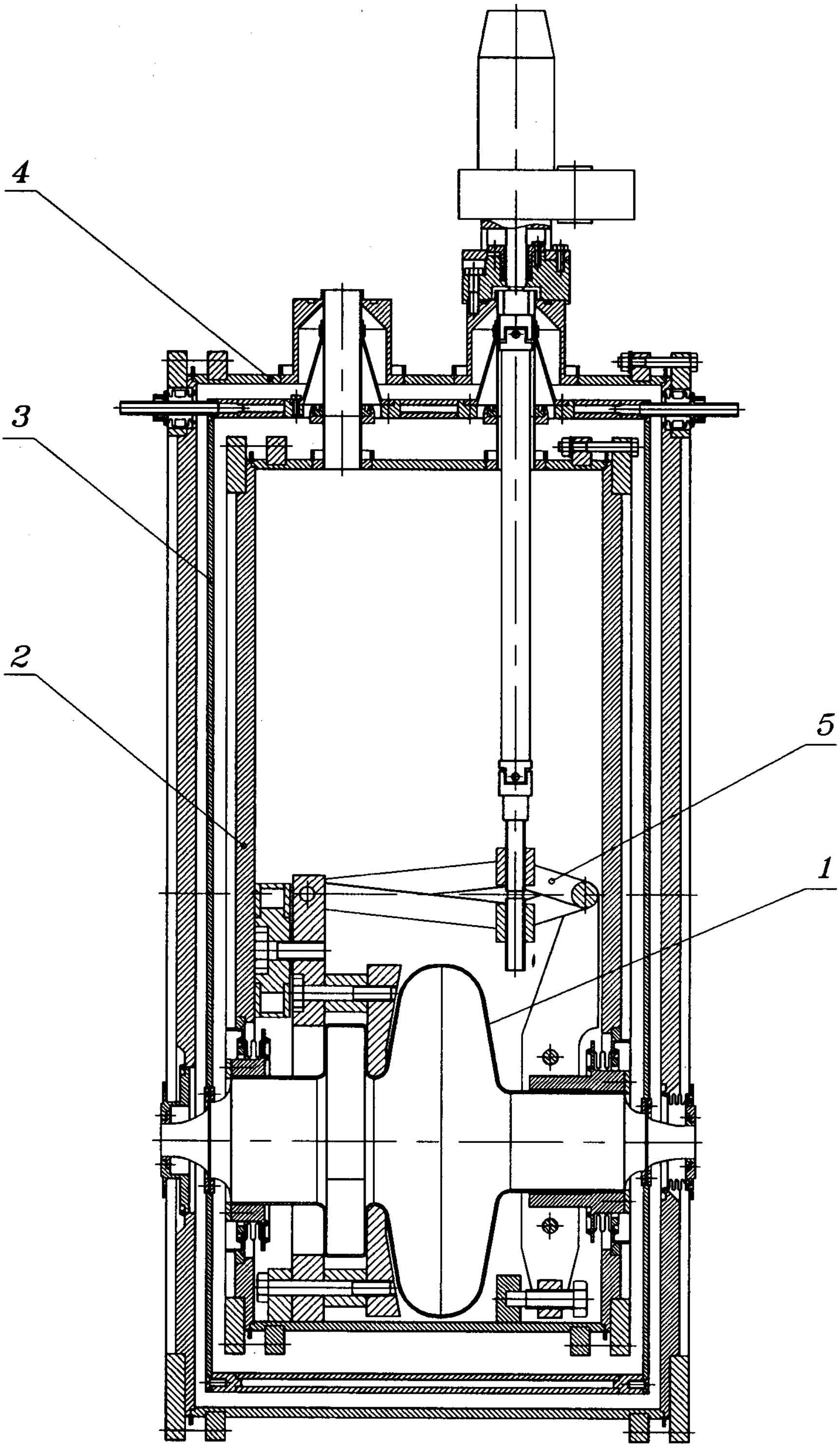

Fig.6: *Design of the cryostat with the BEP cavity*

1 - cavity; 2 - helium tank; 3 - thermal shield (cooled to $LN_2$ temperature); 4 - vacuum tank; 5 - tuning mechanism.

Table 2: Parameters of the BEP superconducting cavity

Fundamental mode frequency $f$ - 724 MHz
Cavity voltage $V$ - 400 kV
Shunt impedance $R/Q$ - 113 Ohm
Geometry factor $G$ - 182 Ohm
Peak electric field $E_p$ - 4.9 MV/m
Peak magnetic field $B_p$ - 10.4 mT
Tuning range $\Delta f$ - $\geq$ 1.3 MHz
Cavity $Q$ - $\geq 0.7 \cdot 10^9$
Operating temperature $T$ - 4.2 K
Total helium loss $P_{he}$ - 6 W

Two niobium cavities of similar shape but without waveguides were fabricated using dying and EBW techniques. Building the set-up for tests of cavities in a vertical cryostat with the diameter of 700 mm is under way. We also plan to conduct first cool tests of the BEP cavity in this cryostat.

## Conclusion

The accelerating niobium RF cavity for the Novosibirsk Φ-Factory is being designed. Its geometry and the HOM damping method have been chosen. Meanwhile, a superconducting cavity of similar geometry for the BEP storage ring has been designed. Simple single cell cavities were fabricated and are being prepared for testing.

## References

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3. V.V.Anashin, S.B.Wasserman, V.G.Veshtcherevich et al. *Electron-positron damping storage ring BEP.* - Preprint 84-114 of the Institute of Nuclear Physics, Novosibirsk, 1984.