IMPROVEMENTS IN THE OPERATIONAL RELIABILITY OF
THE 680 MeV SYNCHRO-CYCLotron AS A RESULT OF THE
MODERNISATION OF ITS RF SYSTEM

K.A. Bajcher, V.I. Danilov, I.B. Enchevich,
B.N. Marchenko, I.Kh. Nozdrin and G.I. Selivanov
Dubna 1972

Translated at CERN by M. Ianovici
(Original: Russian)
Not revised by the Translation Service

(CERN Trans. Int. 72-3)

Geneva
July 1972
Improvements in the operational reliability of the 680 MeV synchro-cyclotron as a result of the modernisation of its rf-system

BAJCHER K.A.  DANILOV V.I.  ENCHEVICH I.B.
MARCHENKO B.N.  NOZDRIN I.Kh.  SELIVANOV G.I.

Abstract

In this work are presented the technical improvements of the rf system of the synchro-cyclotron, the drive (mechanism) of the condenser and the protection of its bearings which have permitted the increase of the working time of the accelerator from 375 hours to 1500 hours and also an increase of intensity from 0.3 μA to 2.3 μA. An analysis is given of the statistical data of the working regime of the rf system as well as of the whole accelerator during 1960-70.

The success of the experimental physics at energies up 1 GeV are due mainly to the steady operation of the 680 MeV synchro-cyclotron of the Laboratory for Nuclear Problems. With respect to its intensity, operational reliability and the technical equipment of its auxiliary devices this accelerator belongs to the best experimental apparatus of its class. A lot of the devices of this accelerator have become as good as an industrial device with respect to their operational reliability.

In what follows we shall present the improvement of one of the most important components of the synchro-cyclotron - its rf system.

Even at the beginning of the work of the synchro-cyclotron type accelerators, where the variation of the frequency is achieved by a rotating condenser, it was clear that the operational reliability of an accelerator of this type is determined mainly by the life-time of the mechanical devices which realize the rotation of the condenser rotor.

The experience of the Dubna synchro-cyclotron operation has shown that the typical processes leading to a breakdown of the rf system are the following:

1. The electro-corrosion of the ball bearings, which takes place when the rf current passes through them and which leads to geometrical distortion of the rotor position with respect to the stator;

2. The heating of the devices rotating on the magnetic field and through which rf currents are also passing, which results in a rapid ageing of the rubber sealing cuff and also an increase in the emission capacity of the metallic surfaces; [3]

3. Decomposition of the oil vapours on the heated parts and the resultant deterioration of the isolation properties of the vacuum intervals between surfaces carrying currents, which leads to the appearance of discharges; [3]

* Translation from the Russian
4. Scattering and transfer of metal due to the electric field, from the heated metallic parts of the rf system to the cooled surfaces of the ceramic isolators.

In what follows we shall analyze the above factors, which influence the operation of the synchro-cyclotron.

The fast deterioration of the ball bearings of the condenser rotor can be explained by two factors: the constructive particularities of the rotor and the difficult working conditions of the whole device. The particularities of the ball-bearing work of the rotor is such that besides the normal statical pressure, they are under the action of other factors such as vacuum, magnetic field, an rf heating and the electro-corrosion of the working surfaces. The work of the ball bearing takes place under condition of a low heat exchange with the surrounding medium and without a sufficient circulation of engine oil.

The last two factors can be considered as constructive particularities of the condenser, and the first two are less connected to the construction. During the operation of the accelerator, and considering that other improvements were achieved, the question of improving the condenser was also raised many times.

The necessity of the improvement becomes very clear if one considers that from 1954 when the SC was rebuilt for 680 MeV to the present time the power given by the rf system has changed from 20 KW to 50 KW.

From the results obtained with a model of the rf system it is known that about 50% of the rf power is dissipated in the condenser.

The increase in the power of the rf system in the first period of its operation has led to a slight decrease in the operation time without a subsequent breakdown (i.e. without deteriorations), as can be seen from the table. Thus, if during 1961-62 this period was 550-600 hours, in 1963 it was only 430 hours. In this way there was an acute necessity for a complex analysis and a removal of the causes of the decrease in the period of operation of the main devices of the accelerator.

In order to find out the main causes of deterioration a large set of data connected with the shutdown periods of the accelerator during 1960-1970 was analyzed. Some of the selected data connected with the work of the rf system are shown in the table, where one can also find some operational characteristics of the accelerator as the main constructive changes achieved at different periods.

Fig. 1 shows a schematic drawing of the rf system with the constructive elements which have the greatest influence on the work of the system.

In the first construction the input of the water into the dee cooling system was made through special stands (15) which introduced an additional capacity in the region of the current bunching of the resonance line.
The replacement of these stands proposed by A.L. Savenkov and the achievement of cooling water inputs through hollow coils with a special inductivity (5), connected to the resonance line in the region of the support springs, has brought about a great improvement in the operation of the rf system: this improvement constituted the increasing of the frequency range through an increase of the upper limit and at the same time a favourable change in the frequency curve shape in the region of the ions capture into the stable orbit. As a result an increase of the intensity from 0.3 μA to 0.8 μA was obtained.

The next improvement was to choose the optimum shape of the condenser stator. This optimization has given an intensity increase up to 1.2μA\textsuperscript{[1,2]}\textsuperscript{12}. It is evident that the intensity increase was obtained by a simultaneous increase of the rf system power which now has the value of 50 kW for the maximum intensity value.

The protection of the rotor bearings against the effect of the rf current passing through them has been achieved by providing a very good contact between the rotating and static parts of the condenser. It was proposed that the earlier existing current collecting ring of squeezing (centrifugal) type which lost its contact properties be replaced because of an improper manufacturing of its friction surface, by a ring with a frontal contact (Fig. 2), provided with springs to compensate the axial displacement of the ring as a result of its exhaustion and also to assure a good pressure of the contact surfaces.

In order to decrease its wear due to friction, the working surface of the stator ring was covered by cement. The rotor ring is made of brass and has a supporting crimp (collar) of 2 mm. height, calculated for a complete exhaustion during more than 5'000 hours of accelerator operation. The collecting of the current from the ring is achieved with a contact elastic petal covered with silver. Apart from the improvement of the bearings protection, action was taken against the loss of oil from the nave (hub) of the condenser rotor. The loss of the oil from the nave (hub) was causing a deterioration of the lubrication process and the cooling of the bearings and creating conditions for the production of discharges in the condenser region.

It is important to note that the compressing (sealing) device with a labyrinth shape, which was introduced in order to stop the oil loss, is working only if the gap between the rotor and the shaft is kept constant. However, any deterioration of the bearings integrity leads to a deterioration of the shaft surface and therefore to a deterioration of the gap magnitude in the compressing device with a labyrinth shape.

In order to overcome this difficulty, a removable ring was set up on the shaft of the condenser in the region of the compressing device. The dimensions of the ring were chosen in conformity with the compressing device and the ring is changed during each ordinary maintenance of the accelerator.

After almost completely solving the problem of the bearing protection, the shutdown of the accelerator for the changing of the bearings has decreased to twice per year. In these conditions, as can be seen from the table, partial shutdowns occur mainly from the necessity of changing some components of the condenser drive mechanism. The average changing of these components with a short shutdown of the accelerator was 6-7 times per year over a number of
years, which is many times greater than the breakdown of other kinds. The
drive mechanism of the condenser is built up of the following components:
the reducer made of two level gears, the cardan shaft, two half-axes with
muffs, supported by three ceramic isolators and the muff of the vacuum sealing
of the shaft output.

As can be seen from the table, the average number of operation hours of the
SC between two successive shutdowns was 800 hours in 1964 and later became
1500 hours. Up to the improvement of the bearings protection, the bearings
had to be removed quite often. In this way a great part of the time of the
maintenance staff was lost on the dismounting and remounting of the condenser
components, which was due to the constructive deficiencies in the execution
of the condenser rotor shaft. The construction of the shaft did not allow the
dismounting of the mechanism on the side of the bearings, and therefore the
reducer had also to be dismounted.

Thus the most important efforts of the operating personnel of the SC were
directed in the last year toward the liquidation of the constructive and
technical deficiencies of the condenser, which precluded its partial dismount­
ing and repair.

With the new construction of the dismountable shaft (fig. 3) this disadvantage
is removed and the repairing time is now half as long, while the operation
of changing the bearings is much simpler.

At the same time the irradiation of the personnel decreased consider­
ably.

One of the components of the condenser, which for a long time has been
suffering very much from the breakdowns, was the ceramic isolators mounted on
two muffs on the half-axes of the cardan shaft (fig. 4). The cause of the
isolators' deterioration was discovered in 1969 to be connected with the
system of fitting the isolators.

In conformity with their design, the isolators are smooth compact cylinders
of ceramic supported by pressing rings into which they are fitted by pressure.
However, as it was discovered in time that the outside ring became larger and it
was possible for the isolators to turn around their own axle, in this way
step by step, some metal was deposited on the surface of the isolators in the
region where they were touching the supporting rings. The metallization of the
isolators' surface led to the formation of conducting regions, to their
overheating, to cracks, fusion (welding) of the surface and finally to electric
spark-over. It was therefore necessary to insert the isolators into their
support in another way. For this purpose, slots were cut in the isolators'
body and some protuberances on the rings. This way of fixing the isolators
in the rings has completely eliminated the possibility of rotation and there­
fore the cause of the deterioration.

Apart from the transformations described above, other protection measures were
taken for the isolators of the cardan shaft muffs (fig. 5) and also for the
passing sealing cuffs which are on the half-axe which is fastened with the
belt pulley of the driving mechanism.
The operational practice of the SC has shown that similar rubber sealing cuffs fixed on the tail region of the rotor cooled with water were seldom deteriorated, while the cuffs of the small gear of the reducer and the cuffs of the belt pulley had a very short life-time. This was due to the unfavourable temperature at which these cuffs were working. For this reason action was taken to protect the cuffs with the isolator and the semi-axe against the heating from rf and inductive currents and also against oil and scattering of metal.

For this purpose the frontal part of the isolators is protected with electrostatic screens from which the current is removed. Apart from this the half-axes and the ball-bearings are enclosed in magnetic screens.

One of the most sensible components of the rf system, with respect to the electrical strength, is the passing isolator through which the generator tension is applied to the rf system. If discharges occur in the region of the feeder the inner surface of the passing isolator is subject to metallization and is covered with carbon produced by the decomposition of oil vapour in the high frequency electric field. As a result of the increasing conductivity on the inner surface of the isolator in the presence of an rf tension, the latter is strongly heated and deteriorated. Therefore in 1967 action was taken in order to improve the operation conditions of the passing isolator. The protection consists of a copper screen introduced into the inner cavity of the isolator at 8 mm from its surface (see fig. 6). In this case the electrical field in the inner cavity is concentrated mainly between the feeder and the screen. The inner surface of the isolator is protected by the screen against the electric field and is no longer subject to the metallization or the action of the oil vapour. As a result of this protection of the passing isolator in this region of the rf system, there are no more deformations of the electric field and in this way the possibility of parasite oscillations appearing in the system is eliminated. From the table it can be seen that during the last years the passing isolator has worked without any breakdown.

In order to decrease the pollution of the vacuum chamber by oil vapour from the high-vacuum pumps, protective nets were mounted in 1968 at the entrance of the branch pipes of the pumps. These nets have decreased the penetration of the rf electric field into the pump cavity and have decreased the effective geometrical volume of the chamber. The nets are made from copper and have cells of 40×60 mm. The introduction of these nets has increased the volume frequency of the chamber and in this way the parasite losses in the rf system of the SC have been decreased. At the same time the conditions of putting the machine into operation have improved and the current-carrying surfaces in the chamber have begun to be less covered by snuff (scale). In the inner cavity of the pumps there is practically no snuff, which is a proof of the effectiveness of the electrostatic protection.

In conclusion, one should note that the work, actions and technical improvements presented in the present paper are far from complete and reflect only the main stages of the SC improvement of the Laboratory for Nuclear Problems. The importance of the result obtained is that apart from increasing the intensity to 2.3 μA, the repetition rate of the maintenance of the devices was highly decreased, so that the operation time between two shutdowns is now 1500 hours.
Fig. 1 - General view of the rf system

1 - bearings; 2 - rotor; 3 - stator; 4 - current collecting ring; 5 - support springs; 6 - support isolator; 7 - outside tube of the resonance line; 8 - rotor shaft; 9 - bearings; 10 - reducer; 11 - water pipe for the rotor cooling; 12 - supports of the dee beam (girder); 13 - spring isolator; 14 - cardan shaft; 15 - stand for the water-cooling.

Fig. 2 - The current collecting ring

1 - ring; 2 - ring; 3 - flange; 4 - flange; 5 - ring; 6 - ring; 7 - ring; 8 - spring; 9 - ring; 10 - finger (pin); 11 - ring; 12 - ring.

Fig. 3 - Rotor shaft

1 - shaft; 2 - screw; 3 - washer; 4 - bush; 5 - gasket; 6 - flange; 7 - flange; 8 - flange.

Fig. 4 - The muffs of the Cardan shaft

1 - muff body; 2 - spring washer; 3 - spring ring; 4 - half-muff; 5 - ball bush; 6 - pivot; 7 -isolator; 8 - bush; 9 - shaft; 10 - screw; 11 - joint pin; 12 - screw for fixation; 13 - dowel.

Fig. 5 - Muff

1 - gasket; 2 - tube; 3 - screw; 4 - washer; 5 - gasket; 6 - body; 7 - bushes; 8 - flange; 9 - bearing; 10 - gasket; 11 - shaft; 12 - lid; 13 - sealing cuff; 14 - gasket.

Fig. 6 - Passing isolator

1 - feeder; 2 - screen; 3 - isolator.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator power [KW]</td>
<td>32</td>
<td>40</td>
<td>40</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Number of rpm. of the condenser</td>
<td>520</td>
<td>560</td>
<td>650</td>
<td>680</td>
<td>680</td>
<td>680</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>690</td>
</tr>
<tr>
<td>Beam current [mA]</td>
<td>0.3</td>
<td>0.8</td>
<td>1.1-1.2</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Operation time hours</td>
<td>4113</td>
<td>5194</td>
<td>5550</td>
<td>4756</td>
<td>5718</td>
<td>5680</td>
<td>5728</td>
<td>5270</td>
<td>5577</td>
<td>6194</td>
<td>4555</td>
</tr>
<tr>
<td>Removal of short-circuits</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charging of the support spring.</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repairing of the condenser drive mechanism</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Changing of the rotor bearings</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Changing of the passing isolator</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance of the accelerator</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of changes of the components of the driving mechanism</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Average operation time between the shut-downs</td>
<td>375</td>
<td>575</td>
<td>615</td>
<td>430</td>
<td>815</td>
<td>950</td>
<td>820</td>
<td>880</td>
<td>930</td>
<td>1250</td>
<td>1500</td>
</tr>
</tbody>
</table>

**Table**: of the operation regime of the SC and maintenance of the rf system for 1960-70

- **Generator power [KW]**
- **Number of rpm. of the condenser**
- **Beam current [mA]**
- **Operation time hours**
- **Removal of short-circuits**
- **Charging of the support spring**
- **Repairing of the condenser drive mechanism**
- **Changing of the rotor bearings**
- **Changing of the passing isolator**
- **Maintenance of the accelerator**
- **Number of changes of the components of the driving mechanism**
- **Average operation time between the shut-downs**

**Constructive changes**
- Installation of the new stator
- Installation of the ejection coil
- Installation of the installation of the new rotor and of the protective nets at the entrance of the magnetic channel
- Increasing of the central gap of the dee. New tubes GU - 45A
- Increasing of the central gap of the dee. New tubes GU - 45A
- Installation of the new rotor and of the protective nets at the entrance of the magnetic channel
- Installation of the screen of the passing isolator
- Installation of the ejection coil