ELETTRA RF SYSTEM UPGRADE PROJECT

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Abstract

The ELETTRA RF system is composed of four single cell cavities each one powered by a 500 MHz 60 kW power plant. In order to satisfy the increasing requirements due to the installation of new insertion devices, a program for the upgrade of the RF system has started. In a first stage the goal is to increase the available power in one of the RF plants to 140 kW. For the RF power generator the options of using a single high power klystron or combining TV IOTs (inductive output tubes) have been investigated. While the klystron is quite a standard solution, the IOT option has been rarely used in scientific applications, although they have been proposed for new machines and it is widely used in the broadcast market. It offers the advantage of higher and almost constant efficiency and redundancy when more tubes are combined. This paper discusses the options for the power plant and gives an overview of the ELETTRA RF upgrade project. The installation and setting to work of the new system is planned for year 2003.

1 INTRODUCTION

The third generation synchrotron light source ELETTRA is currently operated for users either at 2 GeV, 330 mA or at 2.4 GeV, 130 mA. The maximum envisaged storage ring energy is 2.5 GeV. A great deal of investment is continuously being placed in the growth and improvement of the facility as the installation of new insertion devices, the design and construction of a new full energy injection booster and other machine development projects [1].

Since its initial installation [2] the RF system has had no major upgrades. It is composed of four independent 500 MHz 60 kW cw plants, each one powering a single cell ELETTRA type cavity. Each power amplifier is equipped with a 60 kW TV klystron.

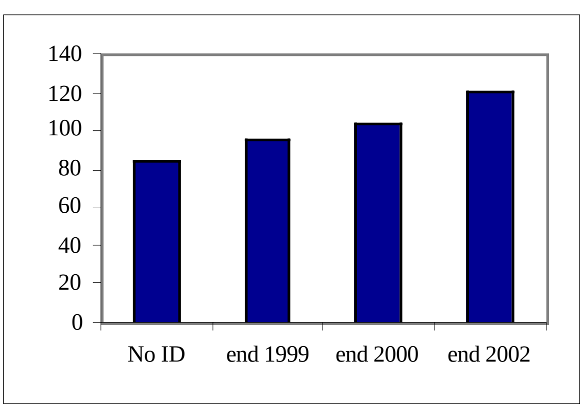

Figure 1: Evolution of beam power requirements (in kW) for 330 mA, 2 GeV.

The recent increase in the number of insertion devices in addition to those planned in the near future substantially increases the demand on the RF power requirements (figure 1). This will reach 121 kW at the end of 2002 for 330 mA stored beam at 2 GeV. The increasing requirements of RF power for the beam have been up to now compensated by decreasing the cavity gap voltage with a consequent decrease in beam lifetime. The lifetime reduction can be recovered following the installation of a third harmonic cavity [3] planned during this year, but the higher required power substantially reduces the safety margins in the RF system operation.

Therefore an upgrade of the existing RF system is necessary to assure:

- An increase of the available power for the beam, also for future new installations of insertion devices or increase of the stored current and energy.
- A higher beam lifetime.
- A wider operating margin for the RF system.

2 THE RF UPGRADE PROJECT

A preliminary study was made to analyse possible solutions for the RF system upgrade, taking account the following conditions:

- ELETTRA is a users' facility, therefore the upgrade has to be gradual in order to minimise the impact on machine operation. For the same reason reliability, long mean time between failures and short repairing time are fundamental issues for all machine components.
- The number of cavities has to remain the same, in order not to introduce new potential sources of multibunch instabilities.
- The upgrade has to be consistent with other facility upgrades, especially the new booster injector where the RF power requirements amount to 55 kW at 500 MHz.
- It has to be compatible with further upgrades such as the possibility to install superconducting cavities.

The result of this work lead to propose an upgrade program divided in three sequential self-consistent phases (named A, B and C). During phase A, one 60 kW RF plant will be replaced with a power plant capable of providing at least 140 kW (120 kW at the cavity input plus the losses in the waveguide). Wasted power in the cavity will be limited to 60 kW (roughly 630 kV RF effective voltage). This will require the replacement of the existing cavity with a similar ELETTRA type cavity having an improved cooling system, which can operate at higher power. The completion of this phase will keep the present performance of the machine, allowing also a slight improvement. All the components of the presently operating 60 kW power plant will be moved to the booster. During phase B the same will be repeated for another plant. This will allow a further improvement both in lifetime and stored current and also could provide a spare plant for the booster RF system. Finally for phase C the possibility of replacing the normal conducting cavities with one or two superconducting ones will be investigated. For this phase two 180 kW RF amplifiers are needed. This phase however still needs further investigation.

At the time being, phase A has been approved and started, while the decision on the two remaining phases will be taken at a later stage. The evolution of Touschek lifetime at the usual operating current and energies is shown in figure 2 (phase 0 shows the status with the existing RF system, vertical scale is in hours).

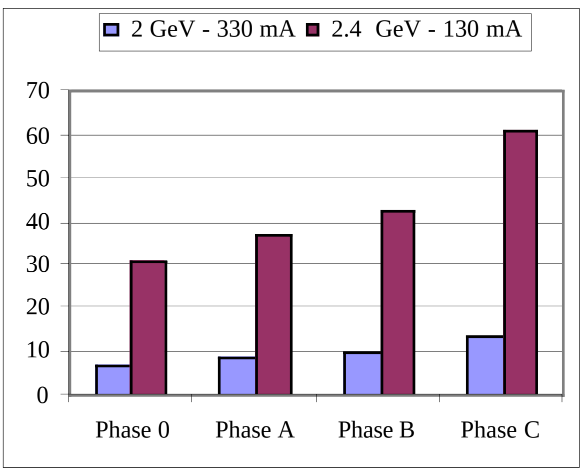

Figure 2: Evolution of Touschek lifetime (in hours).

3 POWER PLANT

For phases A and B, each power amplifier has to deliver 140 kW, while for phase C 180 kW is required from each one. To provide such power, the following options were examined: the use of a single 180 kW cw 500 MHz klystron and the combination of IOTs.

For all the options there is the possibility to have a complete turnkey amplifier provided by industry. The option of combining three 60 kW klystrons of the same type as the ones presently used in the storage ring was soon discarded since, being TV tubes, the efficiency of these klystrons is around 45 %.

The use of a single high power klystron is the standard solution for the power stage of an RF plant in this frequency and power range. 180 kW or higher power 500 MHz klystrons are already installed in different facilities and their reliability and lifetime well known. Efficiency is normally in the range from 60 to 65 % at full power, which drops significantly if the output power is controlled by pure drive modulation as it is done at ELETTRA. Efficiency can however be recovered if anode modulation is used.

The use of IOTs is a novel solution for a light source, although it has been proposed for new machines in construction as DIAMOND [4], [5]. Their use has also been proposed for other types of machines [6]. They are widely used in UHF TV applications due to the higher basic efficiency and the moderate loss of efficiency at reduced power level, but as yet they are rarely used in scientific applications. A single 180 kW cw tube is not yet available, generally the higher power range of existing IOTs is from 50 to 80 kW cw depending on the manufacturer. For this reason it will be necessary to combine two to four of them. Efficiency is in the range from 65 to 70 %, but for drive modulation it does not drop significantly in the power range of interest for ELETTRA (typically from 2 to 3 dB).

The IOT and klystron options were carefully examined and an advisory meeting was organised in Trieste in February 2002. The aim of the meeting was to consider the performance of existing IOTs and make recommendations on their suitability for the upgrade of the ELETTRA RF system. Following these considerations and the discussion during the meeting, the IOT option was adopted.

3.1 Comparison of the two options

The efficiency is higher for the IOT case and almost constant in the output power range of interest for pure drive modulation. This also means that electrical and cooling requirements are lower. The gain however of an IOT is much smaller than for a klystron (typically around 23 dB instead of 41 dB), so the solid state pre-amplifier needs to be rated at much higher power. IOT cathode voltage is lower than for a klystron (typically 35 kV instead of 45 kV), which helps in the reliability of the power supply.

As for physical dimensions, an IOT is much smaller and lighter than a klystron with similar power rating. In the klystron case there will be a single tube while in the IOT case tubes will have to be combined. This implies a relatively complex combining system, which however could be based on the standard solutions adopted for TV transmitters. This also gives the possibility of a multi-stage approach, i.e. starting with less tubes and then adding a further unit when needed.

In the single klystron case, a failure would require interruption of operation till it is fixed. For the IOT case, with a proper design of the combining system and with independent power supplies for each tube, in case of failure of one system the others could continue to work and still deliver power to the cavity, although at a reduced level. If the faulty transmitter could be connected to a load the repair could be done in parallel with machine operation. The increase in number of tubes and related components is in any case quite limited so this is not expected to greatly affect the total reliability of the system. Finally the replacement of an IOT is much faster than that of a klystron.

An important aspect is the reliability and lifetime of the tube. As already stated for klystrons installed in particle accelerators there is a large statistics. For IOTs in cw operation there is little experience. In TV operation the lifetime of IOTs is approaching or is similar to the ones of the klystrons. From the analysis of the two types of operation, it resulted that there is no significant reason why the lifetime should be different for the cw case.

As for the costs, the manufacturing costs of an IOT based system are only slightly lower than those of a klystron based one. In addition the reduced needs in electrical power due to the better efficiency will give a further saving in the running costs. Finally the high power klystron market is restricted to scientific applications, while the IOT market is mature and growing. This gives further advantages in spare parts costs and management.

3.2 System architecture

Since for phase A it is sufficient to provide 120 kW at the cavity input, it has been decided to adopt either a 2 x 80 kW IOTs (150 kW at the combiner output) or a 3 x 50 kW IOTs (140 kW at the combiner output) solution. Both these types of IOTs are already available on the market, used for TV transmission and no developments are required. The system will have an open design to take into account the addition of a further unit in the future if needed to increase the available power. As for the combiner, a standard solution based on switchless combiners will be adopted. The time schedule of the first phase prohibits the development of an IOT combining cavity. Switchless combiners also offer the advantage of only a 3-dB loss when one tube is out of service and ease the servicing of a single unit. The switch between operation modes can be done quickly and also from remote.

4 STATUS AND SCHEDULE

The call for tender of the power amplifier is being issued. Circulator and waveguides will be ordered in parallel with the construction of the power amplifier. During the same time, the necessary upgrades on the RF low level system will be performed. The cavity will be delivered by the end of June 2002. It will be then measured and power tested in the laboratory plant. The goal is to have it ready for the installation in the ring starting from January 2003.

Installation and setting to work of the power amplifier is planned for the second half of year 2003. In order to minimise interference with machine runs, the 60 kW amplifier now powering the cavity will be kept in operation up to the moment of switching between the plants.

5 CONCLUSIONS

The increase of power requirements has lead to the need to upgrade the existing RF system at ELETTRA. The high requirements on reliability and minimisation of the impact on User operation have suggested a multi stage approach. The choice of IOTs for the main power stage is more economical to install and to operate than a scientific klystron. Although not yet extensively used in cw applications, IOTs have demonstrated high level of reliability in the TV market. The first phase of this upgrade, which is required to maintain the performance of the machine, has already started and it will be concluded at the end of 2003.

6 ACKNOWLEDGEMENTS

The authors would like to thank D. M. Dykes, C. David, M. Ebert an H. Frischholz for their participation and valuable suggestions during the advisory meeting held in Trieste on February 28,2002. They also would like to thank the engineering staffs of CPI-EIMAC, Marconi Applied Technologies and Thales Electron Devices for all the information and comments provided.

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