# MEDICAL DEDICATED PROTON SYNCHROTRON

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Photons and electrons are now used for cancer therapy. They are low-LET (linear energy transfer) radiation, so that neutrons, heavy ions and pi mesons are remarkable for their high-LET and large RBE (relative biological effectiveness). Although protons are a low-LET radiation, dose distribution will be greatly improved in tissue, because they have ranges in it and can be manipulated by a magnetic field. As effects of the low-LET radiation in normal tissue are already well investigated, protons will be used in hospitals prior to the high-LET radiation.

The range of 230 MeV protons is about 35 cm in water, so it is sufficient for therapy. However, if the protons are used for diagnosis too, somewhat higher energy is necessary to pass through a human body. Then the maximum energy of the medical dedicated proton synchrotron is determined to be 300 MeV. Thus, it becomes very similar to the 500 MeV KEK Booster.[1] The energy of the extracted beam can be changed easily by changing the extraction timing. Slow extraction is suitable for the proton CT. A beam of $1.5 \times 10^{10}$ pps intensity yields a dose rate of more than 600 rad/min in one liter target volume.[2]

Main parameters of the synchrotron are shown in Fig.1 and Table 1. The combined function type is preferred to simplify tuning of the magnets. Slow cycling of 1 Hz eliminates complexity of the vacuum chamber of a rapid cycling machine. If 30 % of the injected protons are assumed to be accelerated up to the final energy and extracted, then $5 \times 10^{10}$ protons should be injected into the synchrotron. This is achieved by a single turn injection with a 15 mA beam. As the beam intensity of the KEK 20 MeV injector linac is about 10 times higher than the beam intensity above mentioned in routine operation, an injection system of a 10 MeV linac with a 500 kV Cockcroft-Walton preinjector ensures steady operation under the conditions which are much different from that of physics research. To avoid skill for tuning, the aperture of the synchrotron magnet is about two times larger than the expected emittance of the linac beam of $5\pi$ mm-mrad normalized. As the beam of 60 mA is injected into the linac without difficulty, a buncher is not necessary. Then, stabilizers of the accelerating voltage may be omitted in the preinjector. A duoplasmatron ion source lasts more than 2,000 hours without replacement of the cathode.

This injection system, however, has some drawbacks, that is, it needs a large space and is expensive. The cost of the injector is as same as tha of the main accelerator. A radio frequency quadrupole accelerating structure[3] might solve the problem of the preinjector room. When a charge exchange injection system is established technically, a cyclotron, which accelerates negative hydrogen ions up to, say 20 MeV, may be an injector.

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## References

1) H. Sasaki et al., IEEE Trans. Nucl. Sci., NS-24, 1554, 1977.
2) Ch. Leeman et al., ibid., 986, 1977.
3) J.M. Potter et al., IEEE Trans. Nucl. Sci., NS-26, 3745, 1979.

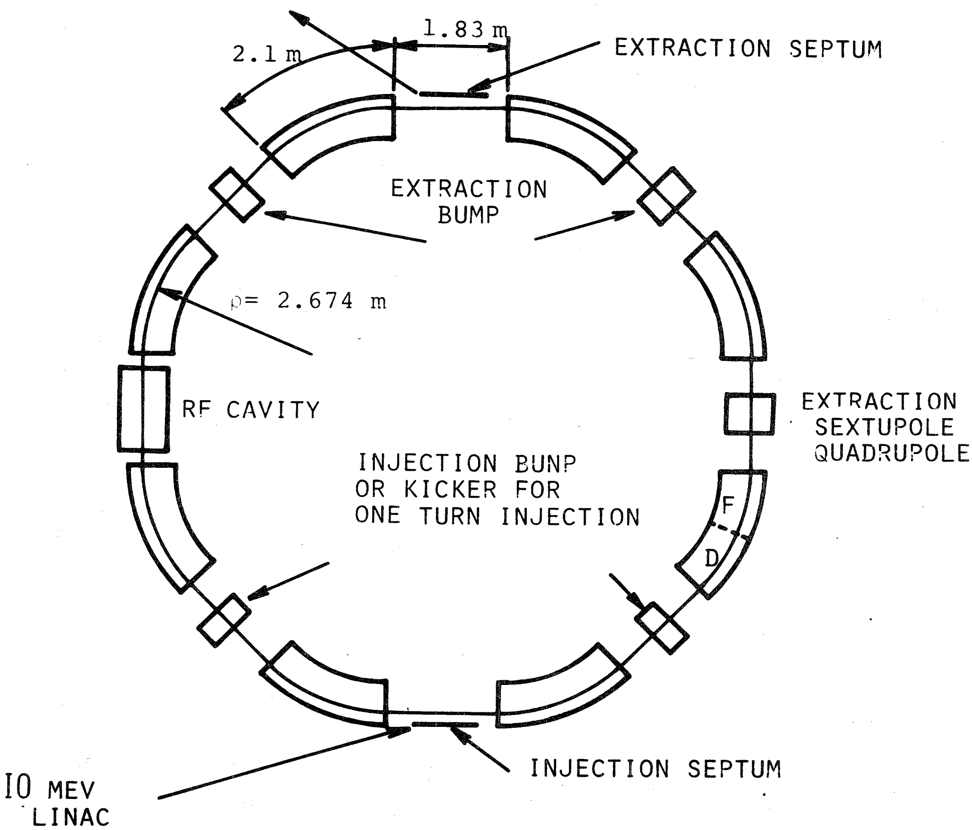


Fig.1 Layout of 300 MeV proton synchrotron.

Table 1

Parameters of Medical-dedicated Proton Synchrotron

| | |
|---|---|
| Type of focusing | Combined-function |
| Focusing order | DFO |
| Injector energy | 10 MeV |
| Injection momentum | 137 MeV/c |
| Injection field strength at equilibrium orbit | 1.7 kG |
| Maximum energy | 300 MeV |
| Maximum momentum | 809 MeV/c |
| Maximum field strength at equilibrium orbit | 10 kG |
| Average radius | 5 m |
| Circumference | 31.4 m |
| Number of periods | 8 |
| Bending radius | 2.674 m |
| Effective bending radius | 2.10 m |
| Length of straight section | 1.83 m |
| Length of focusing sector | 1.05 m |
| Length of defocusing sector | 1.05 m |
| Profile parameter | |
| focusing sector | 2.51 $m^{-1}$ |
| defocusing sector | -2.94 $m^{-1}$ |

| | |
|---|---|
| Number of betatron oscillation per revolution | |
| horizontal | 2.3 |
| vertical | 2.2 |
| Maximum beta | |
| horizontal | 5.9 m |
| vertical | 5.9 m |
| Minimum beta | |
| horizontal | 1.0 m |
| vertical | 1.0 m |
| Maximum dispersion function | 1.68 m |
| Useful semi-aperture of magnet | |
| horizontal | 47 mm |
| vertical | 30 mm |
| Acceptance at 10 MeV | |
| horizontal | 70 pi mm·mrad |
| vertical | 70 pi mm·mrad |
| Revolution frequency | |
| at injection | 1.617 MHz |
| at final energy | 6.031 MHz |
| Harmonic number of RF | 1 |