PULSED DRIFT TUBE QUADRUPOLE MAGNETS WITH HIGH PRECISION

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Abstract

The drift tube quadrupole magnets for KEK 20 MeV injector linac are described. New manufacturing processes of pulsed quadrupole magnets were developed to obtain such a high field gradient as 11 kG/cm, a high reliability and a high precision. The core of the magnet was divided into four quadrant cores. The core leaves were punched by a high precision die set, stacked on a jig and epoxidized to form a quadrant core block. The coils, instead of a wire-winding method, were made of copper blocks by a machining. Four quadrant cores and a coil assembly were assembled on a jig. The deviations of the magnetic centers from the bore center were within 0.02 mm for 90 magnets.

Introduction

Drift tube quadrupole magnets should satisfy such requirements as a high field gradient, a high mechanical precision, a high reliability, a compact structure, and a facility for the manufacturing. The coils should have sufficient mechanical strength, good electrical insulation, and high cooling efficiency, because of high field gradient and high current density under pulsed operations.

The inner surface of the bore tube was chosen as the reference for alignment of the drift tubes. Therefore the deviation of the magnetic centers from the bore centers should be as small as possible. To satisfy this requirement, two methods were considered.

1. Fine adjustment at the time of setting of the quadrupole magnets into the drift tubes.

2. Quality control of the parts and manufacturing processes of both the drift tubes and the magnets.

The latter method has an advantage of reliability and reproducibility of the manufactured magnets.

The total ninety magnets are divided into five groups according the core thickness of 25 mm, 35 mm, 50 mm, 75 mm and 100 mm. Corresponding to the increase of the bore diameter at 29th drift tube from 20 mm to 25 mm, there are two different core profiles A and B (Fig.1). Typical parameters of the quadrupole magnets are as follows.

Drift tube number	1	30	50	90
Gradient, kG/cm	11	6.0	4.3	3.3
Magnet length, cm	2.5	5.0	7.5	10.0
Magnet gap radius, cm	1.1	1.35	1.35	1.35
Peak pulse current, A	700	585	412	320
Power loss, Watts. avg.	130	120	60	60
Number of turns of coil per pole	7.5			
Duty factor of pulsed operation	1300 μs. 20 pps.			

Structure

Four poles of a quadrupole magnet should be symmetrical about the two orthogonal planes including the core axis, and the tips of the poles should be fit into the bore tubes with a negligible clearance. As the core was divided into four quadrants, the pole tip profile and butting surfaces of the quadrant cores were required to have a highest precision.

The coils were machined from copper blocks; accordingly, they have accurate dimensions and symmetry. After assembling the cores and coils on a jig, Al-rings were shrunk on the outer periphery of the cores, and a cooling channel was attached to the magnet. The mechanical reference of the magnets is the tips of the four poles (Fig.2).

Punching of the Core Leaves

The fabrication method of the cores depends on the accuracy of punched leaves, the uniformity of the core thickness, and the magnitude of punched burrs. The mechanical tolerance of the punching die set was within 5μ. The leaves were punched from cold rolled silicon steel belts of 0.35 mm thick (Fig.3). The leaf-by-leaf error of the profile was less than ± 2μ. The punching die set was designed to reduce the punched burrs, however, in order to omit the de-burring process completely, and to obtain a uniform thickness of the cores, it was found that the leaves should be stacked in the same direction as the punching process. To memory the direction, a mark was punched at the outer periphery of the leaves (Fig.1). After inspection, the leaves were degreased by vapour of an organic solvent.

Stacking and Epoxy-Impregnation

For the quadrant cores, the following requirements should be satisfied.

1. Orthogonality between the two butting plane surfaces of a quadrant core $< 10''$

2. Flatness of the butting surfaces < 0.01 mm

3. Perpendicularity of the butting surfaces with respect to the reference end-plane $< 10''$

4. Uniformity of the core thickness < 0.015 mm

In order to satisfy these requirements, the degreased leaves were stacked to form a quadrant core on a jig which consists of a base plate, two rigid square blocks forming the orthogonal reference surfaces and two demountable end-plates (Fig. 4a, b). The leaves were pressed against the reference blocks and compressed to the correct thickness by clamping bolts of the end-plates. The assembly of stacked leaves and end-plates was demounted from the jig and pre-heated to 50°C. Then the lateral surface of the stacked leaves were painted by an epoxy resin. The

Similarly, the user of electron beams for their short pulse high current properties generally has nearly unbounded desires for peak pulse current but usually has very little interest in beam quality provided the beam can be delivered, properly conditioned, to his specified target volume.

It need hardly be mentioned that all users are greatly interested in reliability and construction and operating costs. For those interested in radiation processing and medical therapy this interest is often dominant.

With recognition of the above special situations we have attempted to examine various uses of electron linacs to identify common areas of need where accelerator technology developments might have large user benefits. These uses have been separated into three groups; those where existing technology seems adequate, those where increased duty cycle is important or essential, and those where increased pulsed beam current is important or essential.

Table II lists uses where technology appears adequate. Thus, while better beam emittance and energy spread is often desired for storage ring and most accelerator injectors, the technology to achieve these improvements is well developed. Likewise, while increased average beam current might open some new areas for radiation processing applications, the technology to achieve these improvements is available. The major improvements in this category of application are related to reliability and cost.

TABLE II

LINAC USES WHERE EXISTING TECHNOLOGY IS ADEQUATE

Injectors for storage rings or other accelerators
Cancer therapy with electrons, photons and secondary beam particles
Radiation processing
Activation analysis
Nuclear safeguards

Table III lists uses where increased accelerator duty cycle is important or essential. These are the areas of elementary particle and nuclear research where increasing emphasis is placed upon coincidence experiments. Such experiments will provide unique new information about nuclear and elementary particle structure, and are just barely possible at best with existing accelerators.

TABLE III

LINAC USES WHERE INCREASED DUTY CYCLE IS IMPORTANT OR ESSENTIAL

Elementary particle research
Nuclear physics research
Research with secondary particle beams, positrons, pions, etc.

The highest duty cycle available on currently operating electron linear accelerators is 2 percent on the high duty cycle linac at Saclay, (2) and a projected 5.8 percent for the MIT linac. (3) The electron prototype accelerator (EPA) (4) at Los Alamos Scientific Laboratory operated successfully at 6 percent, and with improved waveguide cooling could have operated at 12 percent duty.

Table IV lists uses where increased pulse beam current is important or essential. In some of these applications linacs are already heavily used, but greater pulse beam current is desired. In other applications increased beam current is essential. For these latter applications pulsed potential drop accelerators are often employed; however, with higher beam currents electron linacs should find application in these areas.

TABLE IV

LINAC USES WHERE INCREASED PULSE BEAM CURRENT IS IMPORTANT OR ESSENTIAL

Production of pulsed neutron sources
Transient chemistry studies
Radiation effects studies and device simulation
Transient radiography
Beam plasma studies
Collective accelerators
Laser excitation
Fusion research

Prospects for Increased Duty Cycle Accelerators

Various different schemes have been proposed whereby high duty cycle electron beams may be produced. The duty cycles possible from these various proposals would vary from roughly 10 percent to a full 100 percent. A summary of these various techniques is given in Table V.

TABLE V

TECHNIQUES FOR INCREASING DUTY CYCLE

Expansion of travelling wave linac technology
Application of new waveguide structures
Superconducting linacs
Recirculation techniques
Pulse stretcher storage rings
Combinations of above techniques

The brute force method of duty cycle improvement by extension of the technology developed for the Saclay or MIT accelerators can certainly be accomplished up to duty cycles of about 10 percent. However, for higher duty cycle this approach would rapidly become more expensive and difficult. To this author some of the alternative approaches discussed below would seem to offer competitive alternatives.

The performance achieved by the EPA standing wave accelerator is quite impressive. This accelerator achieved a 6 percent duty cycle, higher than any operating travelling wave electron accelerator. Twelve percent duty cycle was available from the rf power source, but operation was limited by cooling difficulties which could be corrected.

The relative merits of travelling wave and standing wave structures can be compared by use of an effective shunt impedance (Z_{eff}) defined as

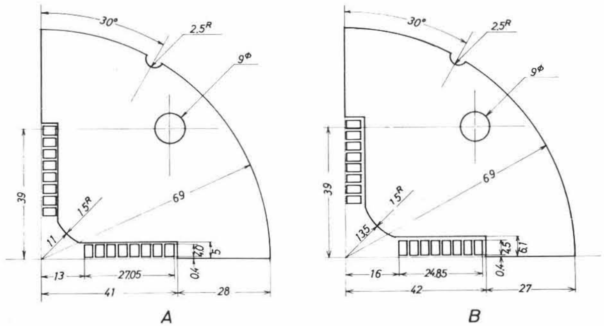

Fig.1 Profiles of punched core leaves.

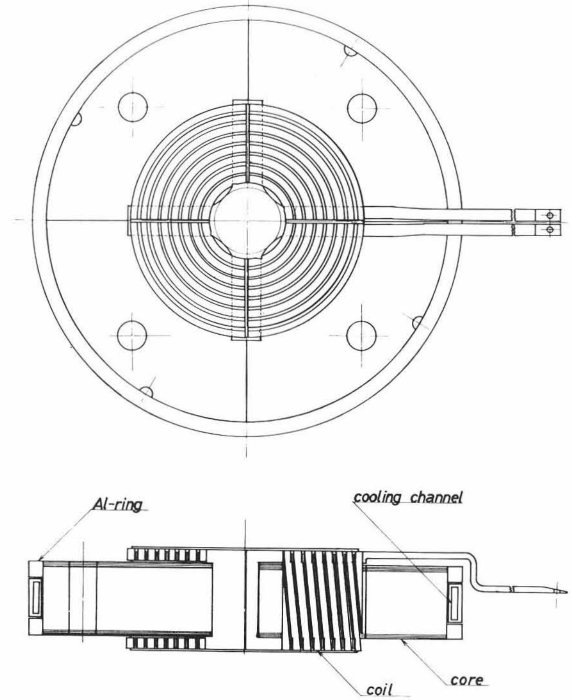

Fig.2 Structure of a quadrupole magnet.

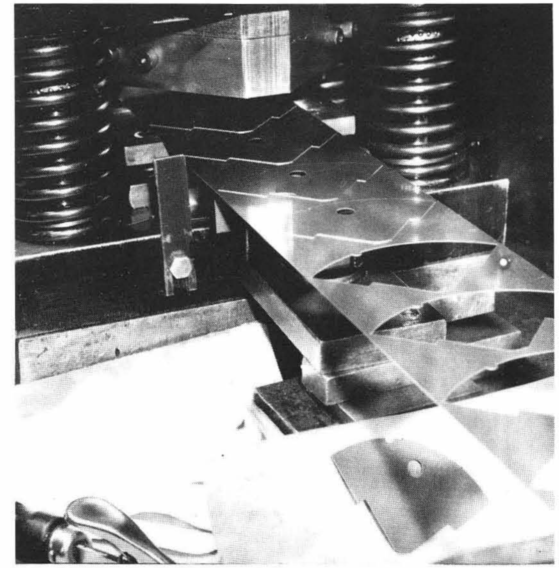

Fig.3 Punching of core leaves.

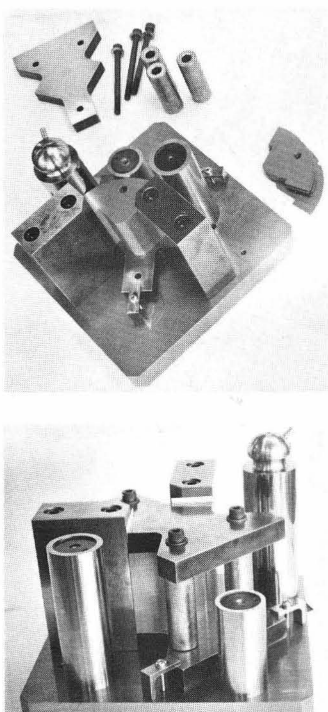

Fig.4 a,b Stacking of quadrant leaves and the jigs.

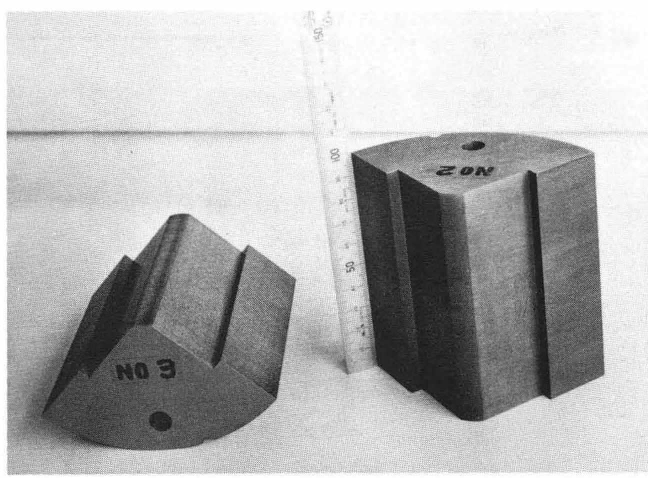

Fig.5 Quadrant core blocks.

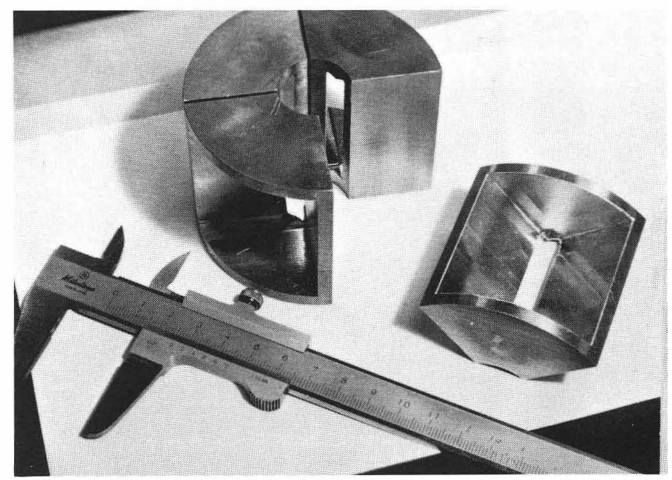

Fig.6 Quadrant coil blocks with the radial hole.

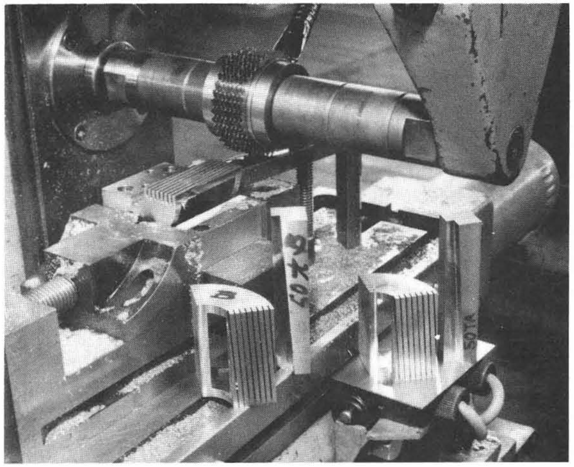

Fig.7 Cutting of the parallel grooves by a milling machine.

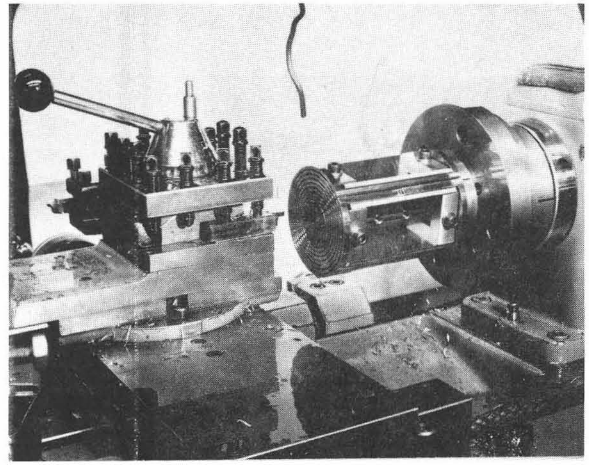

Fig.8 Cutting of the azimuthal grooves by a lathe.

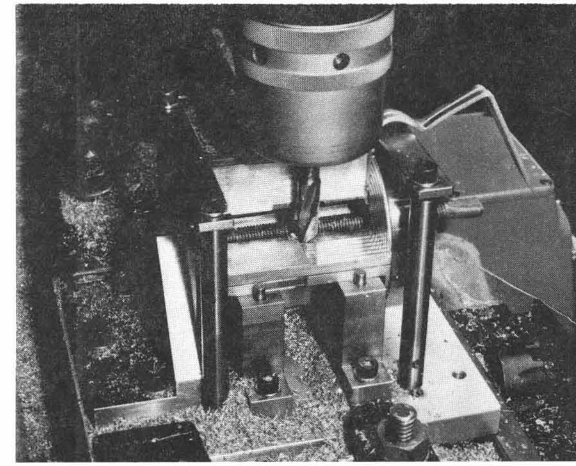

Fig.9 Final machining of assembled coil.

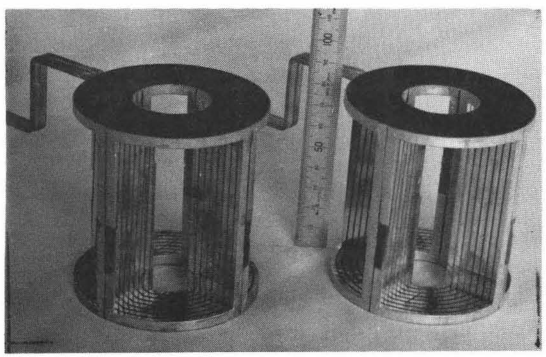

Fig.10 Completed coils.

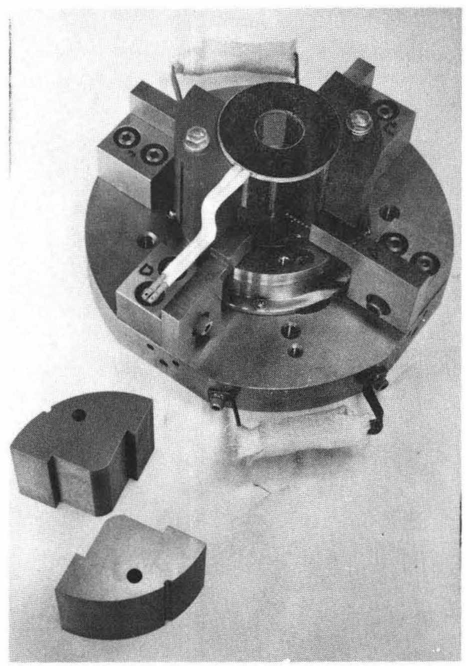

Fig.11 Assembling of the cores and coil on a jig.

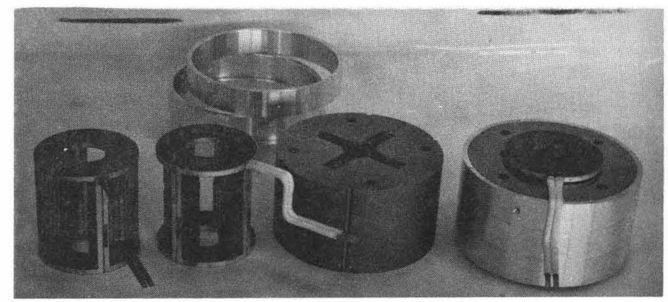

Fig.12 Completed magnet and the components.

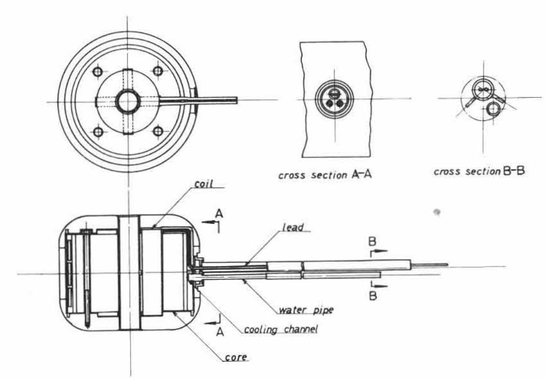

Fig.13 Structure of a drift tube.