THE DESIGN OF THE BEAM DUMPING SYSTEM OF THE CERN INTERSECTING STORAGE RINGS*

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1. Introduction

At 28 GeV and at the design intensity of 20 A, the kinetic energy in each beam of the ISR is approximately 1.8×10^6 J. If, for instance, a power failure on the ISR magnet occurs, the stacked beam will spiral outwards at a rate of only 1.3 micron per revolution. Most of the protons would then be absorbed in a small region of the ISR vacuum chamber where the closed orbit is nearest to its outer wall, so that a severe risk of damage to the vacuum chamber would exist. Localized beam losses can also be caused by errors in the excitation of one of the many ISR correction elements, or by beam blow-up in case of a sudden pressure increase in the ISR vacuum chamber. Therefore, it is necessary to have a simple and reliable system which can dump the beam whenever safety circuits indicate faulty operation or excessive beam loss. The same beam dumping system will, of course, also be used for scheduled beam dumping in order to concentrate the beam loss as much as possible in a small region of the ISR and to reduce the induced radioactivity elsewhere.

The stacked beam in each of the rings of the ISR will be dumped by means of four fast pulsed magnets in which the magnetic field is made to rise within 200 nsec to the minimum value required to deflect the beam over 2 mrad onto the dump block. The dumping magnets will give a vertical deflection to take advantage of the fact that the beam height is small in the mid F long straight sections, independent of the stacked beam current. The pulsed magnets and dump blocks for each ring will be placed at the upstream and downstream ends respectively of the 16.8 m long straight sections near crossing point 3. The distance

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* Доклад не зачитывался.

between the centre of the four magnets and the dump block is 10 m. Each of the four magnets in each ring is energized independently by its own pulse generator. Each pulse generator consists of a pulse-forming network (PFN) switched by a triple gap deuterium thyratron which generates a rectangular pulse of about 200 nanoseconds rise time and 3.6 microseconds flat top duration. Each magnet will be placed in its own bakable ultra-high vacuum tank. The dump will consist of a titanium alloy core surrounded by a steel shielding. A prototype 60 kV pulse generator with a magnet of reduced length has been tested and has shown the expected performances.

2. General design and choice of parameters

The main requirement for the pulse shape in the dump magnets is a fast rise time, while the rest of the pulse shape is not critical. The present design is based on the use of a full aperture horizontal field magnet with a window of 150 mm horizontal and 40 mm vertical. Such a magnet has a small inductance as compared to a vertical field magnet of the same horizontal and vertical aperture and length, which leads to a small impedance value. The impedance and other main parameters are given in the following table:

TABLE OF PARAMETERS

Beam vertical displacement	20 mm
Beam deflection angle	2 mrad
Total kick strength	0.2 Tesla×metre
Number of magnets	4 (per ring)
Magnet length	1.33 m (each)
Magnet vertical aperture	40 mm
Magnet horizontal aperture	150 mm
Characteristic impedance	3 Ω
DC working high voltage	45 kV–50 kV
Current of each pulse generator	7.5 kA–8.3 kA
Magnetic field rise time (expected)	180 nanoseconds
Pulse duration	4 microseconds
Flat top duration	3.6 microseconds
Beam dump block length	2.5 m
Distance between magnet centre and dump	10 m
Maximum repetition period	5 seconds

3. Design of the pulse generator

After the pulse has attained the minimum necessary value to send the beam onto the dump block it can be made either to stay constant or to continue to increase thus sweeping the beam across the dump blocks. The first shape of pulse, i. e. a rectangular pulse has been chosen beacuse it can be generated by a pulse-forming network (PFN) of well-known design. Moreover, this obviates the problem of reflections in the transmitting cables, and it also gives the lowest charge to switch.

A rectangular pulse can be generated either by a charge cable or a lumped element network. Although the former gives a better flat top the second solution is acceptable for this application as it results in a more compact and less expensive equipment. The number of sections was chosen to be 11. All sections have 3 low inductance capacitors in parallel except the first which has four, each of these four capacitors having a resistor in series to improve the rise time. The capacitors have an oiled paper-polycarbonate dielectricum. Figure 1 shows the prototype outside its oil tank. The PFN is discharged by a deuterim triple gap thyratron CX 1171 fabricated by English Electric Valve Company. Figure 2 shows the general circuit of the beam dumping system.

4. The magnets and vacuum tanks

Due to unusual ratio of gap height and width it has been possible to choose an air-core magnet rather than a ferrite core magnet. This air-core magnet consists of two parallel horizontal plates connected together by short end pieces. Figure 3 shows the prototype magnet. The design criteria of the magnet are a good transverse homogeneity of the kick strength, a low total inductance (including connections) and a simple construction. The non-uniformity of the kick strength (i. e. $\int B_H \, dz$, B_H being the horizontal magnetic field and z the coordinate along the beam axis) is acceptable for the present application ($\simeq +6\%$). The parallel plates magnet has also a lower inductance than a ferrite magnet of the same length but its deflection is a factor 0.75 smaller for the same current. The conductors of the magnet are made of stainless steel. Each magnet is located in an ultra-high vacuum stainless steel tank of 45 cm diameter and 135 cm length. It is fixed in place by alumina insulators and a machined girder attached to the upper part of the vacuum tank. The pumping system consists of one 400 l/s sputter ion pump and one 70 l/s turbomolecular pump for two tanks and one sublimation 500 l/s pump per tank. The bakeout of the tanks will be made in removable ovens at temperatures of up to 300°C.

5. The beam dump blocks

When the stacked beam is directed onto an absorber material it generates nuclear showers within this material and its energy is transformed into heat. According to a Monte-Carlo calculation[1] the rate of energy loss on the beam axis due to primary protons, secondaries and evaporation particles may be as high as 20 MeV/g—cm^2 per incident proton. The total length of absorber material will be 2.5 m. The integrated intensity of low energy particles at the downstream end of the block will be a factor 500 less than the intensity of the incident stacked beam.

The temperature in the dump block will instantaneously rise to relatively high values in the volume where the beam is absorbed. The maximum temperature as well as the temperature distribution inside the block depend on its density, on the absorption mean free path, and on its specific heat. If the material is completely constrained and if the elastic limit is not exceeded and remains constant the thermal stress is roughly $\sigma_{th} = \alpha E \Delta T$ (with α—thermal expansions coefficient, E—Young's modulus). For the region where the energy absortion rate is very high, titanium or a titanium alloy has been chosen, because it fits well the requirements on yield strength, specific heat, thermal expansion coefficient and outgassing rate. For a 20 A stacked beam with a cross section of 70 mm×10 mm maximum temperature increase of about 350°C and the stress of the order of 30 kg/mm^2 has been estimated. For the rest of the block steel is adequate.

6. Experimental work on prototypes

A prototype 60 kV pulse generator with its PFN and its CX 1171 thyratron, and a prototype parallel plates magnet of 80 cm length have been built. The magnet was placed in a vacuum tank in which a pressure of 10^{-5} Torr was maintained to hold the voltage. A ferrite magnet of the same length has also been built for comparison. Seven 21 Ω pulse cables in parallel, of 10 m length, connect the pulse generator to the magnet. In order to get a good matching a 30 Ω carbon resistor is placed at the input of the vacuum tank, between the cables and the feedthrough. This tank input is electrically insulated by compressed nitrogen.

The magnetic measurements were made with a long loop and a passive integrator. A zero method has been used. The magnetic field pulse is shown in Fig. 4. The shape of the pulse is as predicted. The rise time is about 110 nanoseconds for the prototype parallel plates magnet. It was 160 ns for the ferrite magnet of the same length. One cannot see mismatch effects caused by the inductive part of the load, The flat top is sufficiently constant for beam dumping. Since the final parallel plates magnet will be130 cm long instead of 80 cm for the prototype, the expected rise time for the final set-up is about 180 nsec. Extensive measurements of the field uniformity were made on different models of parallel plates magnets in order to optimize the conductor geometry. Figure 5 shows the cross-section adopted for the 80 cm long prototype magnet with its resulting distribution of the kick strength. The nonuniformity does not exceed +6% up to a point 7.5 cm from the beam axis.

The thyratron used as a switch has many advantages[2] but has the disadvantage of a long delay between the moment of triggering and firing of the pulse of the order of 0.5 microsecond for the CX 1171. This will give an increased beam loss in the case of a spontaneous breakdown of one of the four thyratrons because even when the three other thyratrons are triggered by the erratic breakdown of the first the deflection of the beam will not be sufficient for dumping during this 0.5 microsecond. A long test of voltage holding has been made at 60 kV with the complete prototype set-up. This test consisted of a pulse test and a DC test. During the pulse test the repetition rate was one pulse per 40 seconds and 10^4 pulses of 10 kA have been achieved with only one case of erratic breakdown. DC test was a stand-by test at 60 kV and the complete set-up has held the voltage without spontaneous breakdown for a total of 40 hours. These life time tests will be continued with other CX 1171 thyratrons.

In parallel with the work on pulse forming networks.switched by thyratrons, the use of spark-gaps has been investigated. The main problem of spark-gaps used as switches is their low reliabilty, i. e. their high rate of erratic breakdowns. We have built and tested a three-electrode field distortion spark-gap similar in design to the spark-gaps used at Culham Laboratory[3,4]. We have also built and briefly tested a four-electrode field distortion spark-gap of a new design[5] which had as main objective to improve its reliability for high current switching. These spark-gaps have been tested with the 3Ω prototype PFN and give a rise time which is 10 nsec shorter than that with the CX 1171 thyratron. The main advantage of spark-gaps for the beam dumping system would be that one spark-gap can switch the four PFN's together so that the risk of having one quarter of the desired deflection during 0.5 microsecond in case of an erratic firing of a thyratron is avoided. The work on spark-gaps will therefore be actively pursued.

7. Control aspects

The controls aspects of the beam dumping system are still under active study. However, the following situation which necessitate the dumping of the beams can be listed:

1) A fast rate of change of the stack position due to a failure in the excitation of the main magnets and/or the auxiliary magnets of the ISR.

2) A fast rate of change of the stack dimensions due to a fast growth of the betatron oscillations, e. g. in case of a sudden pressure increase.

3) A too high rate of change of the stacked beam current as measured by ISR beam intensity monitors.

4) Accidental closing of one of the vacum sector valves.

5) Radiation danger for personnel.

6) Scheduled manually operated beam dumping.

Conclusion

A fast system to dump the proton beam of one or both of the rings of the ISR has been designed with special emphasis on reliability. The dumping system of each ring consists of four air-core parallel plates magnets. These magnets of a very simple design which are each excited by a rectangular current pulse from a pulse generator, deflect the beams vertically towards dump blocks situated in the same straight section of the

ISR so that the irradiated area remains localized. The pulse generators will be switched by triple gap deuterium thyratrons, but in parallel development work on spark-gaps is actively pursued. A comlete prototype set-up with one pulse generator and its magnet has been tested up to 60 kV and has shown the expected performances.

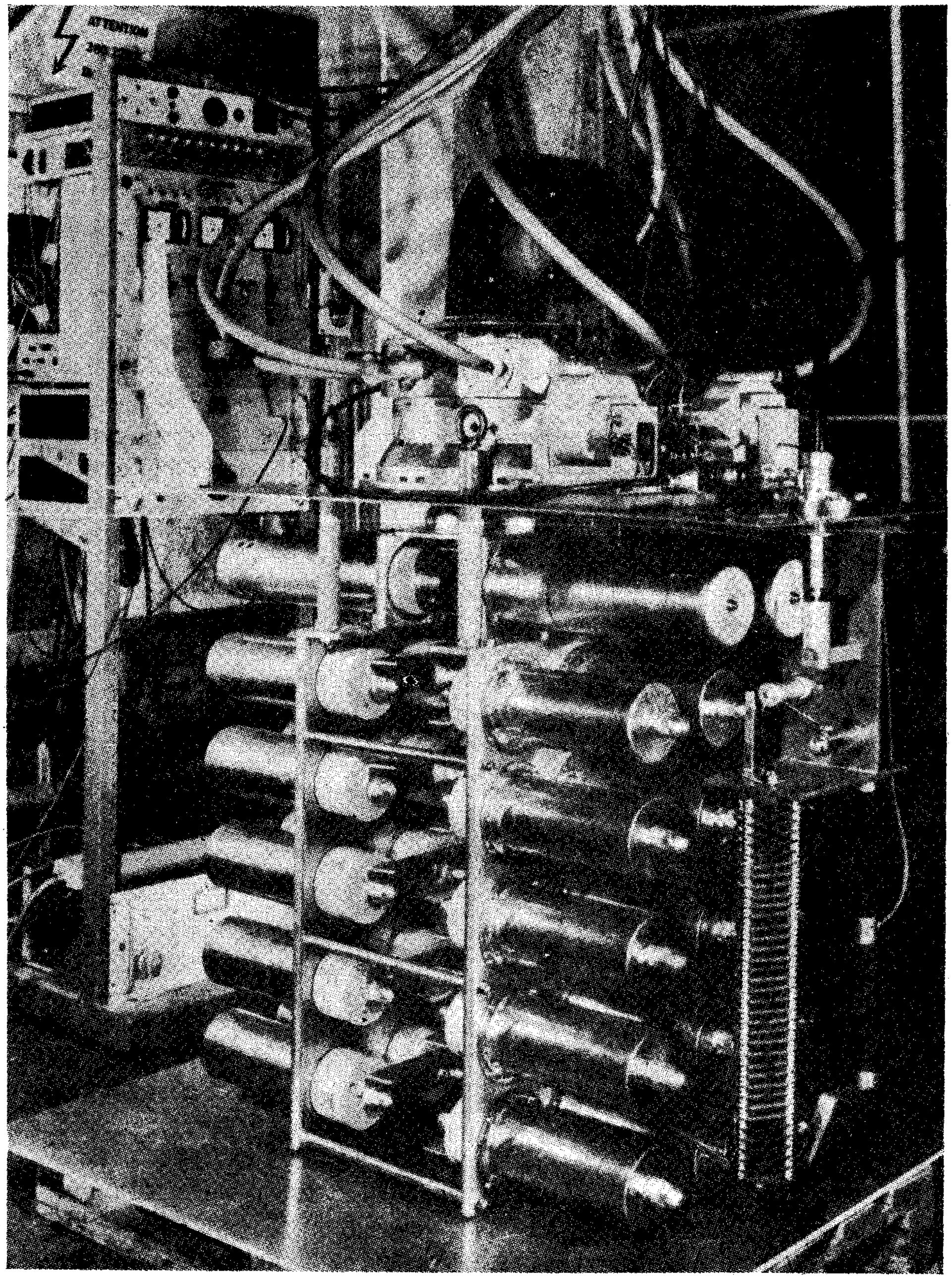

Fig. 1. General view of the prototype FN

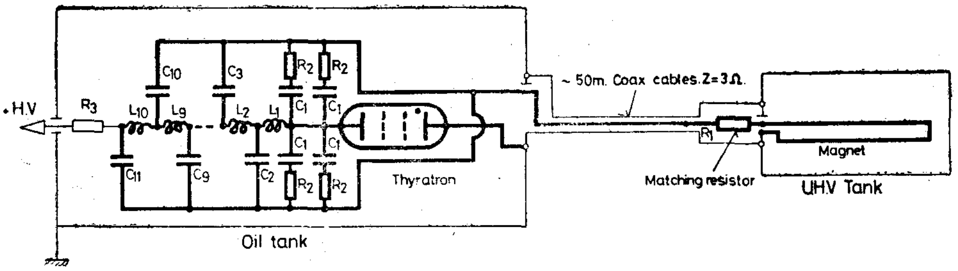

Fig. 2. Beam dumping circuit

Capacitor LCC

$C_1=20000$ pF, 60 kV.

$C_2-C_{11}=60000$ pF (3×20000 pF). 60kV

$L_1\simeq900$ nH.

$L_2-L_9\simeq550$ nH.

$L_{10}\simeq700$ nH.

$R_1=3$ Ω (Load resistor)

$R_2=6$ Ω

$R_3=1$ MΩ

Thyratron E. E. CX 1171

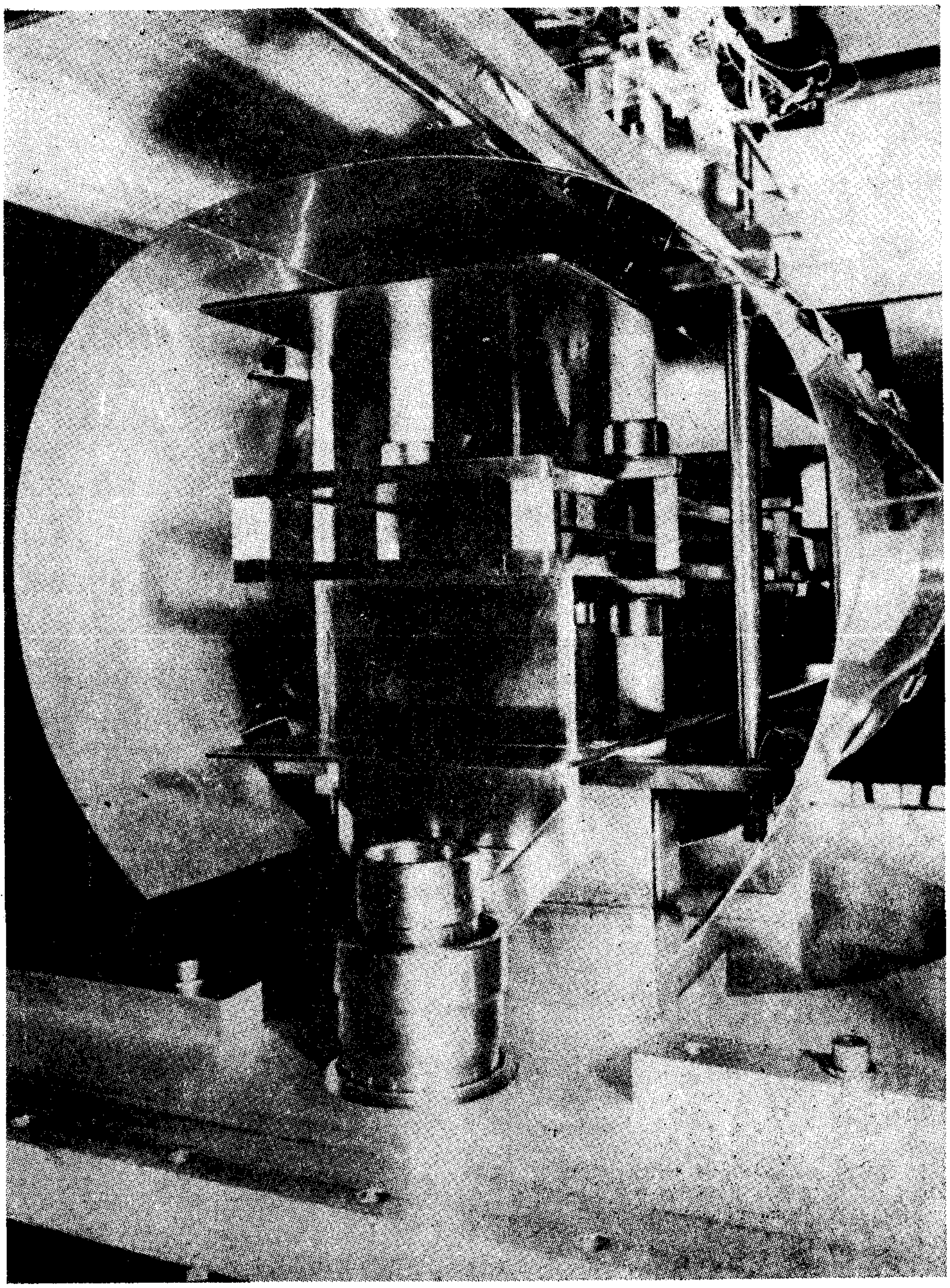

Fig. 3. Prototype parallel plates magnet

One can see the two horizontal plates connected by short end pieces. The connections to the feed-through are also parallel plates in order to get the minimum inductance. The sheet around the magnet simulates the vacuum tank.

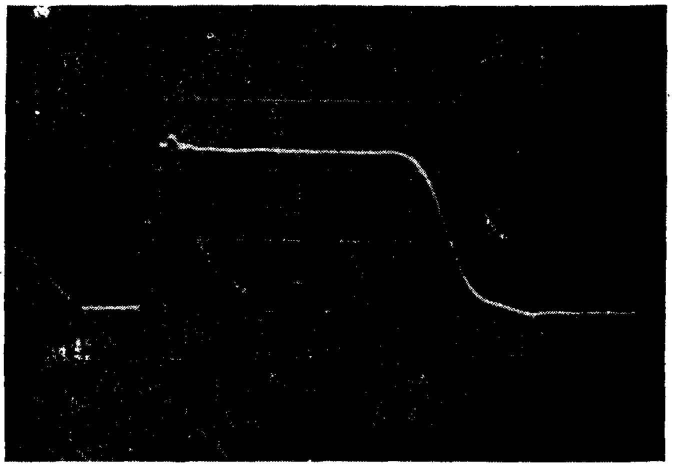

Fig. 4. Magnetic field pulse shape given by the parallel-plates magnet. (The horizontal scale is 0.5 μsec/cm).

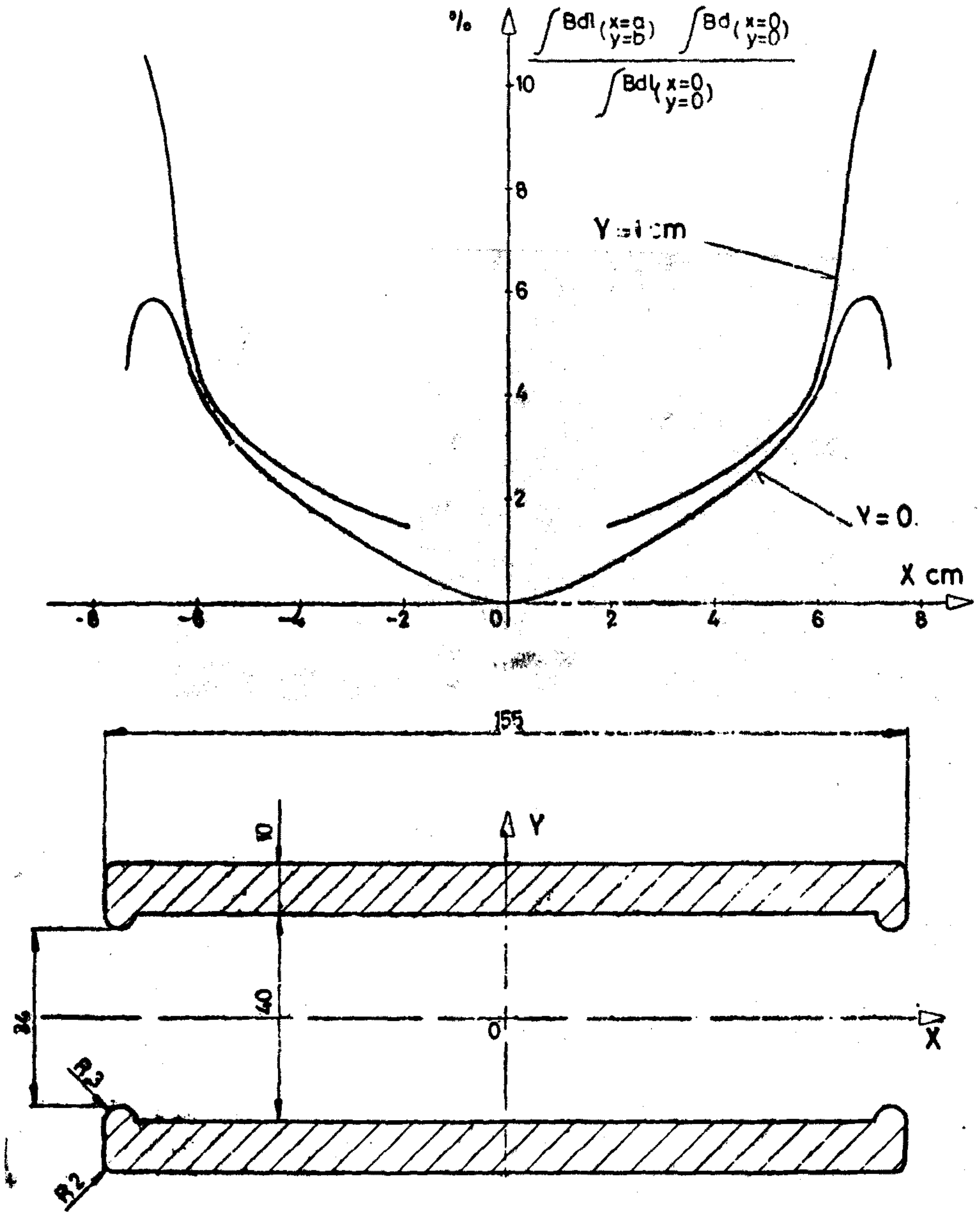

Fig. 5. Distribution of the kick strength over magnet cross section. Magnet length 815 mm.

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