NEUTRON VELOCITY SELECTOR OF THE INSTITUTO DE ENERGIA ATÔMICA MECHANICAL DESIGN AND ELETRONIC CONTROL

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NEUTRON VELOCITY SELECTOR OF THE INSTITUTO DE ENERGIA ATÔMICA
MECHANICAL DESIGN AND ELECTRONIC CONTROL

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Resumo

Foi construído no Instituto de Energia Atômica, um seletor de velocidade para neutrons, tipo Fermi, a fim de eliminar reflexões de ordem superior num monocromador de cristal e também tendo em vista experiências nas quais é necessário um feixe de neutrons lentos de alta intensidade. O rotor foi idealizado para selecionar neutrons muito lentos, ainda que a resolução seja pobre, visando a obtenção de um feixe intenso. Tomaram-se providências para se reduzir o background de neutrons e raios gama. Apresenta-se o seu projeto mecânico, acrescentando-se algumas considerações quanto ao projeto dos rolamentos. É descrito o sistema automático de contrôle de velocidade, que consiste de um motor D.C. de 5 H.P., alimentado por um retificador trifásico, controlável, a thyratrons. A velocidade é controlada por um sistema eletrônico com realimentação negativa. A estabilidade, em pequenos intervalos de tempo, é cerca de 0,5% depois do aquecimento. No começo da operação, é fornecida uma corrente constante.

Résumé

On a construit à l'Instituto de Energia Atômica un sélecteur de vitesse pour neutrons, type Fermi, pour éliminer les reflexions d'ordre supérieur dans un monochromateur à cristal et aussi destiné à des expériences où on

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a besoin d'un faisceau de neutrons lents de haute intensité. Le rotor a été projeté pour sélectionner neutrons très lents, bien que la résolution soit pauvre, ayant pour but l'obtention d'un faisceau intense. On a pris des mesures pour réduire le bruit de fond de neutrons et de rayonnements gamma.
On presente son projet mécanique et on ajoute quelques considérations sur le projet des roulements. On décrit le système automatique de contrôle de vitesse, qui consiste dans un moteur D.C. à 5 H.P. alimenté par un retificateur triphasique, controlable, à thyratrons. La vitesse est controlée par un système électronique avec réalimentation négative. La stabilité dans de petits intervalles de temps est de 0,5% après le réchauffement. Au commencement de l'opération, on fournit un courant constant.

Abstract

A Fermi-type neutron velocity selector was constructed at the Instituto de Energia Atômica (IEA) to eliminate higher order reflections in a crystal monochromator and for experiments where high intensity beams of very slow neutrons are required. The rotor has been designed to select very slow neutrons, although with poor resolution, in an effort to obtain an intense beam. Provisions were made to reduce neutron and gamma ray background. The mechanical design is described and some considerations about the bearings design are added. The automatic speed control system is described, and consists of a 5 HP D.C. motor powered by a controlled three-phase thyratron rectifier. The short term stability is about 0.5% after warm-up. For start-up, a constant current of operation is featured.

INTRODUCTION

IEA has a small neutron spectrometer (built from an x-ray monochromator) which has been used in the last two years to measure the slow neutron total cross section for some rare earth elements. Every crystal monochromator has the problem of contamination of the neutron beam with energies higher than that of the first order Bragg reflected neutrons. These higher order reflections occur at energies $4E_o$, $9E_o$, ... where E_o is the first order energy usually desirable.

One way to eliminate the undesirable neutrons is to pass the beam (either before or after the Bragg reflection) through a Fermi-type mechanical velocity selector. Such selector cannot conveniently be made with high enough resolution to replace the crystal monochromator entirely, but their use make the possible elimination of unwanted orders with a relatively low loss in intensity of the first order neutrons.

For this purpose, and for certain other experiments where high intensity beams of very slow neutrons are required, a Fermi mechanical velocity selector was constructed at IEA. In the section that follows, the mechanical design is described. In later sections, the operating characteristics and electronic controls are described.

DESIGN

Figure 1 shows a schematic of the rotor. The shaft (horizontal at IEA) is a 4.5 inch diameter steel shaft with multiple bearings about 36 inches between centers. The bearings are mounted in rubber which serves to align the bearings and to damp out vibrations. The bearings are cooled by circulating oil.

The neutron beam is defined by 30 slotted disks equally separated by 29 plastic spacers. Each steel disk has 36 slots, each of them having 3/8 x 1 inch. These disks may be arranged to define the neutron velocity with the resolution required by a particular experiment.

The rotor is operated in a vacuum of about 1000 microns Hg in order that the power dissipation is not excessive. The peripheral speeds are less than the velocity of sound, so that the residual air does not heat the rotor.

The bearings are commercial high speed ball bearings rated for continuous service at 13000 rpm. The rotor has operated routinely at speeds up to 11000 rpm with vibrational amplitudes completely negligible, and with no bearing failures. The individual disks were balanced before assembly of the rotor to assure vibration free operation at high speed. The resonances in the loaded shaft are at frequencies much higher than the design maximum, which is 15000 rpm.

The number of neutrons transmitted by this rotor when adjusted for a velocity resolution ($\frac{\Delta v}{v}$, where v is the full width of the transmitted spectrum at half height) of .20 is given by the expression

$$2.3 \times 10^7 \xi^4 e^{-\xi^2},$$

where is the ratio of the transmitted neutron velocity to the most probable velocity (defined by $1/2\ mv_0^2 = kT$). Conditions at the IEA reactor are arranged so that a radiating surface of about 12 in^2 is available near the center of the reactor core about 150 inches from the velocity selector. The reactor flux there is 2.5×10^{12} n /cm^2/sec.

The background counting rate in a direct beam experiment is designed to be less than about 1 count/minute using a proportional counter of dimensions 1/2 inch diameter by 1-1/2 inch long, filled with 70 cm BF_3 gas with no enrichement. Such a detector is essentially 100% efficient for neutrons whose velocities are less than 1/20 thermal. The efficiency for detecting neutrons of thermal energies is less than 2%. The background of 1 count/minute was chosen as comparable to that normally expected from natural radioactivity in the detector walls.

Besides choosing a detector whose efficiency is low for neutrons of thermal energies, the limit of background also dictates the amount of steel in the rotor necessary to attenuate the high flux of epi-thermal neutrons. Using the numbers already given, the amount of steel required is 7.5 inches. Because approximately half the steel in the disks is cut away to form slots, the rotor was designed with 30 1/2-inch disks giving 7.5 inches of steel in the path of a neutron whose velocity is fast compared to the velocity being selected. The steel disks were cadmium plated to stop neutrons of velocities slightly above or below the selected velocity. The cadmium also serves to absorb neutrons thermalized in the apparatus, neutrons which might otherwise multiply scatter into the detectors.

A plastic stator (not shown in the schematic) was formed from 30 plastic plates, formed in such a way that every alternate plate occupied the region between the steel disks. Slots were cut straight through these interleaving plates so that no neutrons could pass outside the rotor teeth. The rotor-stator spacing was 1.0 mm over the full length of the rotor and over about 1/3 of the periphery of each steel disk.

In the design, every effort was made to reduce the flux of fission neutrons, epi-Cd neutrons, thermal neutrons, and reactor gamma rays. It is thought to be possible to perform direct beam experiments with neutrons whose energy is a factor 100 less than thermal with a counting rate comparable to the background, that is, 1 count per minute.

Figure 2 shows the number of neutrons per second transmitted for each rotor velocity, when the rotor is adjusted for a resolution of $\frac{\Delta v}{v} = .20$. For low velocity, this curve is also the direct beam counting rate, and the dashed curve shows the counting rate in a proportional detector filled with 70 cm normal BF_3 (Anton 821).

The rotor has been designed to select very slow neutrons with poor resolution with an effort to increase the intensity. It is easy to readjust the steel disks so that a smaller slot is defined (by staggering alternate disks) and in this way neutrons of energies higher than thermal may be selected at practical rotor velocities. Of cource this method of adapting the rotor for higher velocity neutrons reduces the intensity in proportion to the square of the reduction of the slit width, but near the peak of the Maxwellian intensity is no problem in a direct beam experiment.

ELECTRONIC SPEED CONTROL

The rotor of the selector is powered by a standard 5 H.P. 220 V DC shunt motor through a V belt system.At the maximum speed (10.000 rpm in the rotor), the motor is run at about 2000 rpm and 250 V in the armature and field. This is about 20% overdrive but is not detrimental to the motor.

The speed control is made through the armature current fed by a tri--phase rectifier.

The thyratrons are of the Phillips type PL105 with power supplied from a tri-phase line with 220 V phase-neutral. Each thyratron is controlled by a variable time delay circuit that provides a turn-on trigger pulse with a delay, related to the beginning of the positive part of the wave. This delay is controlled by the voltage furnished by a D.C. amplifier, so that a variable portion of the positive wave may be rectified giving thus a continuously variable rectified power from zero to the maximum.

The speed control is done by negative feedback, with a speed sensing device, an operational amplifier and the above described controlled power rectifier.

The speed sensing is done by an A.C. generator attached to the rotor shaft, whose signal is rectified after passing through a current transformer that gives a direct current proportional to the speed. This current is subtracted from a fixed reference current and fed to a D.C. amplifier of current feedback type. The speed is adjusted by a precision potentiometer in the generator circuit, which controls the generated current. This sensing system was a low cost temporary solution, to be replaced later by a D.C. tachometer generator.

The stability is good for short periods (~0.5% in 30 min.) showing a steady drift for the first 30 minutes, which is attributed to temperature effects in the resistance of the generator circuit.

To calibrate and monitor the speed, a scaler is used to count the number of generator cycles for a given period of time.

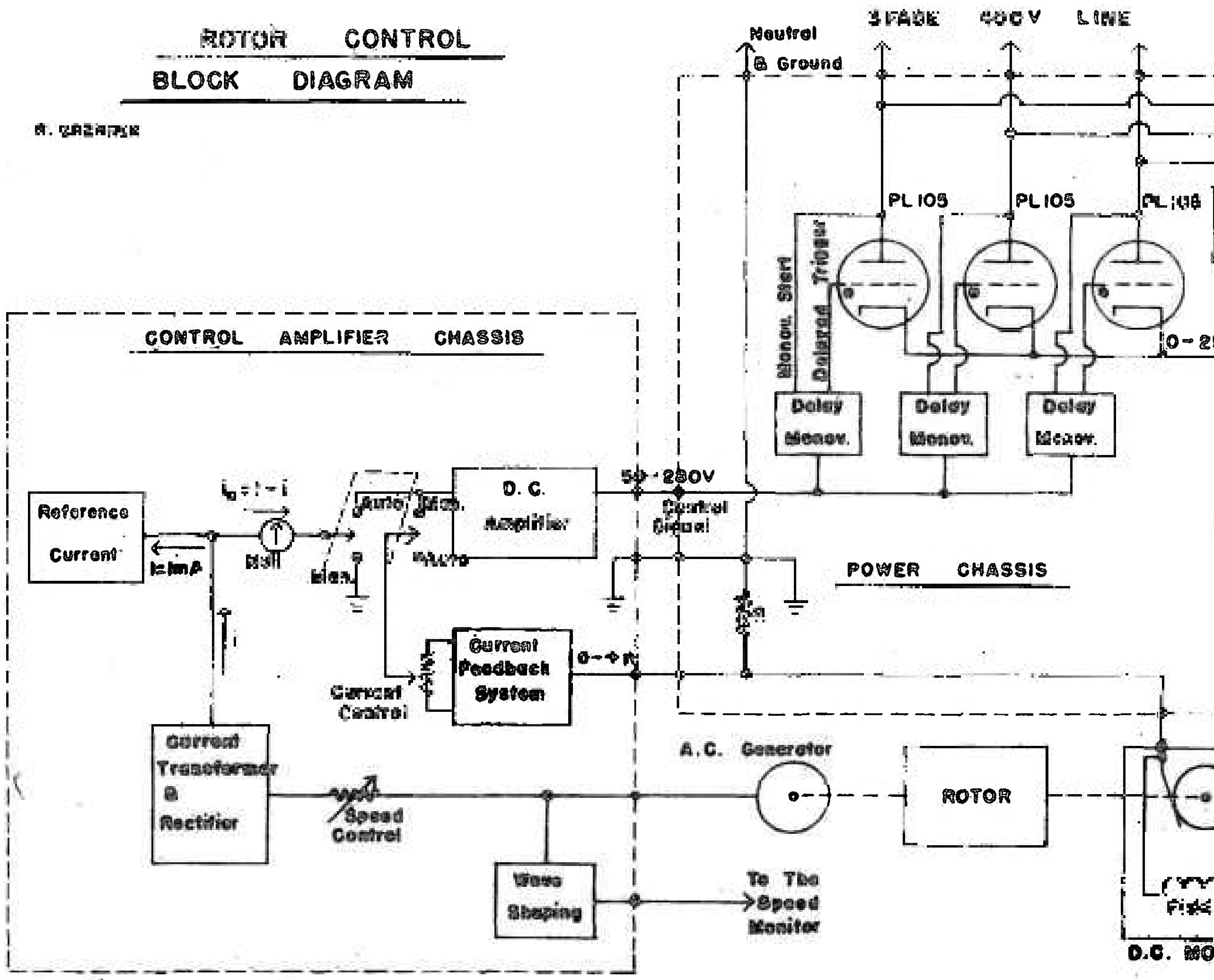
For the start-up, an armature current feedback system that by-passes the speed control is used, supplying to the armature a constant manually-controlled current, independent of the speed. A null indicator is used to show when the speed has reached the desired control point.

The control system was built in two separate units as can be seen in the block diagram.

SOME PROBLEMS RELATED TO THE BEARINGS DESIGN

In the first design, the bearigns were mounted rigidly on the housing which is a heavy and rigid structure. Since the rotor is heavy and the shaft very short and rigid, this mounting created two important problems:

1) The rotor unbalance, which is not too small and difficult to eliminate as a result of the multi-parts structure of the rotor, developed a strong vibration that consumed excessive energy with evident danger to the system.


ROTOR CONTROL
BLOCK DIAGRAM
Neutral
& Ground
3 FASE
400 V
LINE
PL 105
PL 105
Monov. Start
Delayed Trigger
Delay Monov.
Delay Monov.
Delay Monov.
CONTROL AMPLIFIER CHASSIS
Reference Current
I=1mA
Null
Bias
Auto
Man.
D. C. Amplifier
50 - 280V
Control Signal
POWER CHASSIS
Current Feedback System
Current Control
Current Transformer & Rectifier
Speed Control
Wave Shaping
To The Speed Monitor
A. C. Generator
ROTOR

2) The ball bearings showed a rapid deterioration owing to the increased vibrational load and also due to high speeds and rigid mounting, the bearing tracks surface tending to deteriorate. Thus a flexible mounting was decided on, with a vibrating mass attached to the bearing as small as possible. Each bearing consists of a pair of SKF 6205 ball bearings encased in an 8 cms. diameter, 10 cms. long iron cylinder with an oil seal at each bearing. This cylinder was mounted in a cylindrical hole in the housing, with an anular spacing of approximately 6 mm and two neoprene "O" rings tightly inserted into the spacing.

The space between the ball bearings is filled with oil, which is circulated through a water heat exchanger by a pump, the latter directly connected to the rotor system in order to prevent overheating following an eventual power failure.

This mounting was very effective, the system having a single broad resonant frequency of about 3500 rpm with good damping, no noise, and at other speeds the vibration having disappeared almost completely, even with the rotor not finely balanced.

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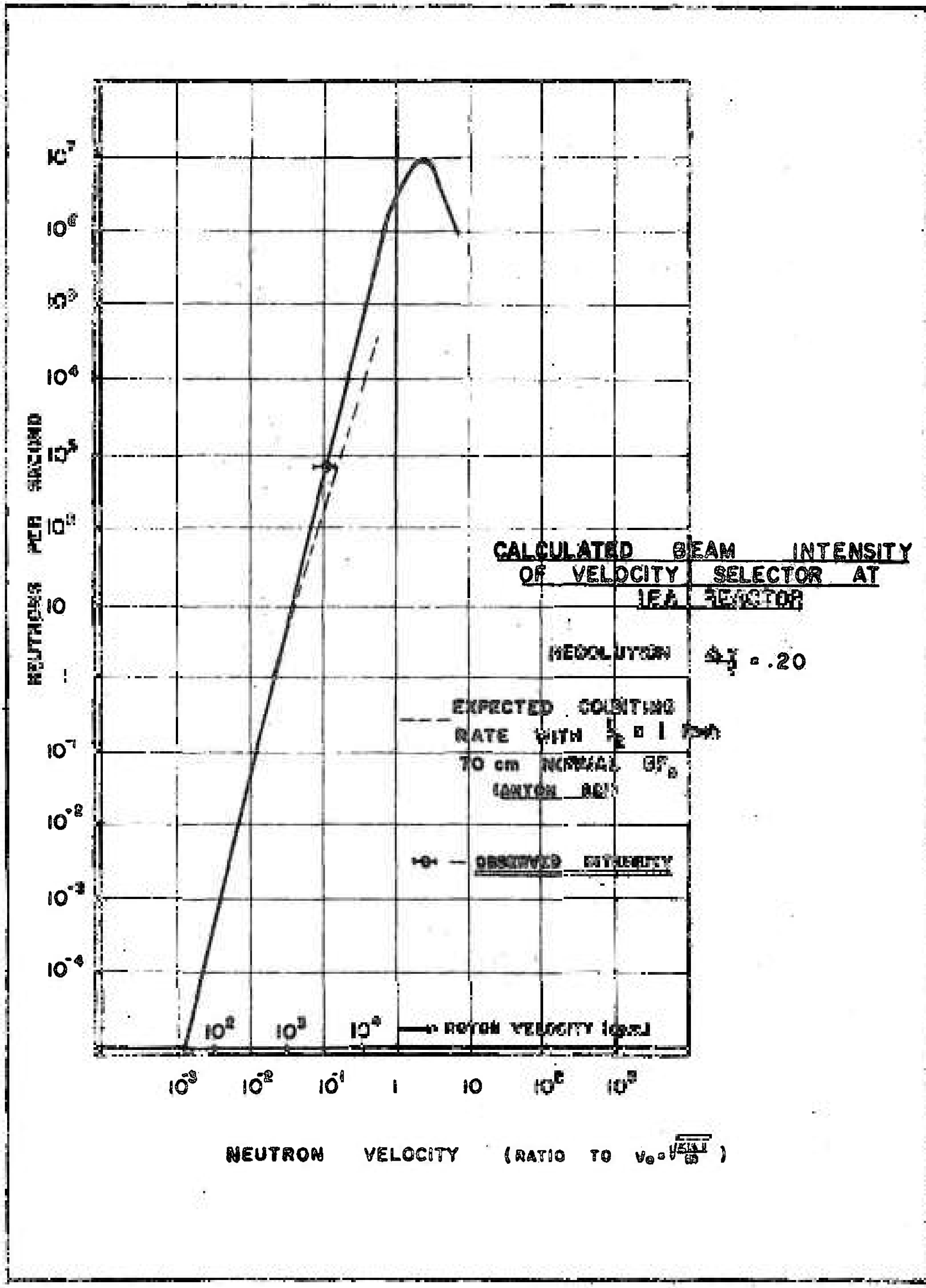
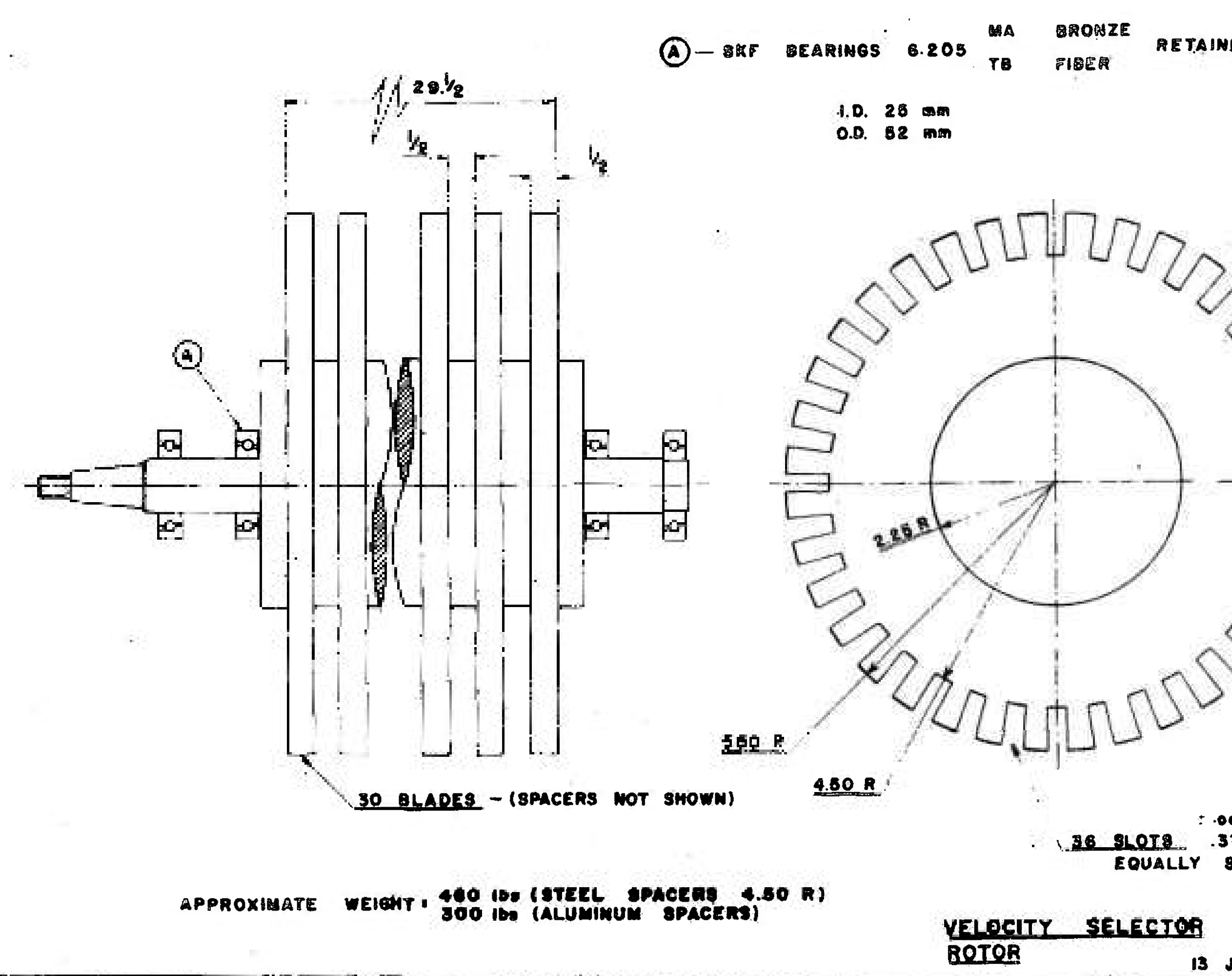

CALCULATED BEAM INTENSITY
OF VELOCITY SELECTOR AT
IEA REACTOR
NEUTRONS PER SECOND
10⁷
10⁶
10⁴
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
EXPECTED COUNTING
.20
10²
10³
10⁴
10⁻³
10⁻²
10⁻¹
1
10
10²
10³
NEUTRON VELOCITY (RATIO TO



(A) — SKF BEARINGS 6.205 MA BRONZE RETAINE
TB FIBER
I.D. 25 mm
O.D. 52 mm
29 1/2
1/2
1/2
A
2.25 R
5.60 R
4.50 R
30 BLADES – (SPACERS NOT SHOWN)
36 SLOTS .3
EQUALLY S
APPROXIMATE WEIGHT: 460 lbs (STEEL SPACERS 4.50 R)
300 lbs (ALUMINUM SPACERS)
VELOCITY SELECTOR
ROTOR
13 J