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(J. A. Fox)

4 G.e.v. Electron Synchrotron

Resonant Magnet Network

Proposed control and accuracy requirements for magnet guide field

National Institute for Research in Nuclear Science
Electron Laboratory

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Summary

These notes describe the accuracy requirements of the magnet guide field and the proposed method of control.

1.0 Magnet Field

The biased, time varying, magnet guide field is of the form:-

$$B(t) = B_{DC} - B_{AC} \sin \omega_a t$$

The unidirectional component of field (B_{DC}) is provided by the D.C. bias power supply and the sinusoidally varying field component (B_{AC}), by the pulse power supply[1].

The accelerator nominal frequency of 50 cycles/sec. is substantially constant for a given magnet excitation, and has a maximum excursion of 0.17% due to capacitor dielectric temperature changes in the resonant network. These dielectric temperature changes occur slowly over a time interval of several hours.

2.0 Field control requirements

It is necessary to control two field parameters:-

(a) Peak field $\hat{B}$
(b) Field gradient at injection $\dot{B}_{INJ}$

where $$\hat{B} = B_{DC} + B_{AC} \qquad (1)$$

and $$B_{INJ} = B_{DC} - B_{AC} \sin \omega_a t \qquad (2)$$

It is proposed that for all peak field values $(\hat{B})$, particle injection shall always occur at the same field amplitude (B_{INJ}) and gradient $(\dot{B}_{INJ})$

The given values are:-

$B_{INJ} = 70$ gauss

and a $\dot{B}_{INJ}$ corresponding to $\hat{B} = 9000$ gauss, $B_{DC} - B_{AC} = 40$ gauss

i.e. $B_{INJ} = 4520 - 4480 \sin \omega_a t$

$\dot{B}_{INJ} = 0.16259$ gauss/μ sec.

We can therefore tabulate, for a range of $\hat{B}$ values, the corresponding values of B_{DC} and B_{AC} that provide the required gradient at an injection amplitude of 70 gauss. Since:-

from (2) $$\sin \omega_a t = \frac{B_{DC} - B_{INJ}}{B_{AC}} \qquad (3)$$

and
$$\dot{B}_{INJ} = -\omega_a B_{AC} \cos \omega_a t$$
$$= -\omega_a B_{AC} \left[1 - \left(\frac{B_{DC} - B_{INJ}}{B_{AC}} \right)^2 \right]^{\frac{1}{2}}$$
$$= -\omega_a \left[B_{AC}^2 - B_{DC}^2 - B_{INJ}^2 + 2 B_{DC} B_{INJ} \right]^{\frac{1}{2}} \qquad (4)$$

Using (1) and substituting for B_{AC} in (4) we obtain:-

$$\dot{B}_{INJ} = -\omega_a\left[\hat{B}^2 + 2B_{DC}(B_{INJ} - \hat{B}) - B_{INJ}^2\right]^{\frac{1}{2}}$$

i.e. $$\dot{B}_{INJ}^2 = \omega_a^2\left[\hat{B}^2 + 2B_{DC}(B_{INJ} - \hat{B}) - B_{INJ}^2\right] \qquad (5)$$

and hence from (5)

$$B_{DC} = \frac{\hat{B}^2 - B_{INJ}^2 - \dfrac{\dot{B}_{INJ}^2}{\omega_a^2}}{2(\hat{B} - B_{INJ})} \qquad (6)$$

and $B_{AC} = \hat{B} - B_{DC}$

giving tabulated values (where $\omega_a = 2\pi f_a = 100\pi$)of:-

$\hat{B}$	B_{INJ}	$\dot{B}_{INJ}$	B_{AC}	B_{DC}	$B_{MIN} = B_{DC} - B_{AC}$
9000 gauss	70 gauss	0.16259 gauss/ sec.	4480	4520	40
8000 "	"	"	3981.89	4018.11	36.22
7000 "	"	"	3484.4	3515.6	31.2
6000 "	"	"	2987.59	3012.41	24.82
5000 "	"	"	2492.17	2507.83	15.66
4000 "	"	"	1999.08	2000.92	1.84
3000 "	"	"	1510.7	1489.3	-21.4
2000 "	"	"	1034.41	965.59	-68.82
1000 "	"	"	608.98	391.02	-217.96

It will therefore be necessary to provide servo systems, acting on the B_{AC} and B_{DC} excitation sources, that control either directly or indirectly the quantities $\hat{B}$ and $\dot{B}_{INJ}$

3.0 Accuracy of Field control

Peak Field. It is proposed to control the peak field to an accuracy of 0.01%, for a range of peak field settings 1000 to 9000 gauss, and this accuracy must be maintained for a period of several hours.

Field gradient at injection. The allowable tolerance in field gradient at injection is not accurately known at present, but it is expected that an accuracy of $\dot{B}_{INJ}$ to within 2 or 3% will be acceptable.

Ripple. The total field ripple content from either rectifier commutation of the magnet power supplies, or any other source, shall not exceed 0.5 gauss peak to peak during the rising portion of the magnet field waveform.

4.0 Proposed method of control of $\hat{B}$ and $\dot{B}_{INJ}$

It will be necessary to control $\hat{B}$ and $\dot{B}_{INJ}$ via the excitation sources of B_{DC} (DC bias power supply) and B_{AC} (pulse power supply).

Now if we neglect saturation we may write the field function $B(t)$ in terms of the excitation current waveform $I_m(t)$:-

$$I_m(t) = I_{DC} - I_{AC} \sin \omega_a t$$

Consequently two possible methods of controlling the required parameters exits:-

(a) sampling I_{DC} and I_{AC}

(b) sampling $\hat{B}$ and $\dot{B}_{INJ}$

<u>Sampling I_{DC} and I_{AC}</u>

This system is shown in the simplified block diagram of Fig. 1, a brief description of which is as follows:-

Two separate servo loops exist, one for I_{DC} and one for I_{AC} both have independant and adjustable references. The I_{DC} control loop obtains a continuous sample of the DC excitation current from a shunt or D.C. transformer situated at the DC bias power supply input point, this signal is compared with a reference and the error drives the grid gear (or magnetic amplifier) of the DC bias mercury arc rectifier power supply (or silicon rectifiers) via the amplifier chain.

The I_{AC} control loop is essentially a discontinuous sampling servo system (data sampling) which measures the positive peak value of I_{AC} , once per cycle, from a back leg winding on one of the guide field magnets. This signal is compared, via the "data hold" device, with a reference and the resultant error drives the grid gear of the pulse power supply rectifiers thus controlling the charge on the energy storage capacitor

If I_{DC} and I_{AC} are independantly controlled to an accuracy of 0.01% the tolerance for a peak field setting of 9000 gauss will be:-

$$\Delta B_{DC} = 0.45 \text{ gauss}$$
$$\Delta B_{AC} = 0.45 \text{ gauss}$$

and hence the variation in the field gradient at injection :-

$$\Delta \dot{B}_{INJ} / \dot{B}_{INJ} \doteq 1.5\%$$

When setting the excitation requirements for a particular experiment, the servo references I_{DC} and I_{AC} will be adjusted by the operator to the required values from comparison with instruments that measure the magnetic field directly.

One final point should be made in respect of the I_{DC} network. The sampling point must be free of both DC source ripple and the AC cyclic loss pulse current increment. The former will be suppressed by matching of rectifier and filter characteristics and the latter should not appear if the resonant network remains truly symmetrical, but this will require experimental verification.

<u>Sampling $\hat{B}$ and $\dot{B}_{INJ}$</u>

Since the required accuracy can be achieved by excitation current sampling a more complicated system based on direct field measurement should be unnecessary. However, since some consideration was given to this it is briefly described in the following paragraphs and shown in simplified block form in Fig. 2.

Two coupled servo loops exist with outputs to both the DC bias and pulse power supplies. The $\hat{B}$ servo loop comprises a data sampled signal which is compared with a peak field reference, the resultant output is then fed, via amplifiers, to the control devices of the DC bias and pulse power supplies. The B_{INJ} servo loop obtains its data sampled signal by timing the rate of rise of field between two biased peaking strips biased either side of the B_{INJ} field amplitude, and located in one of the magnet gaps. The period elapsing between the operation of the low and high set peaking strips is converted into an electrical signal (proportional to the period) and compared with a $\hat{B}_{INJ}$ reference. The resultant signal is fed via a further set of amplifiers to the DC bias and pulse power supply control devices.

It will be noted that while the $\hat{B}$ error signal actuates both DC bias and pulse power supplies in the same sense, the $\hat{B}_{INJ}$ error signal drives these two excitation sources in opposite polarities. Furthermore, the $\hat{B}$ reference is adjustable while the $\hat{B}_{INJ}$ reference is fixed.

The system has two possible short-comings. Firstly, due to the different circuit dynamic characteristics seen by the source power supplies (see fig. 3, the DC bias network has a time constant of approx. 3 secs. and the pulse power supply feeds a network with a Q of approx. 100) stabilisation to the accuracy required may be difficult. Secondly the interdependance between peak field amplitude and the gradient at injection is the only restraint against gross amplitude instabilities. Consequently failure of either control loop would require instant suppression of both excitation sources.

5.0 Ignitron control in pulse power supply

The energy storage capacitor C_f will be discharged by the ignitron, via the pulse choke L_p and the energy storage choke L_{ch} so that the resulting current pulse i_p occurs approximately symmetrically around the positive peak of the magnet voltage V_m (see fig. 4).

The ignitron firing control shall be phase controlled so that the firing instant is independant of slight excursions in accelerator frequency ω_a and this phase control shall be manually adjustable.

The phase controlled ignitron firing shall have an accuracy of $\pm 0.1^\circ$ and the jitter shall not exceed 1 μ second.

6.0 Conclusions

The following action is therefore proposed.

A servo control system will be developed on the basis of sampling I_{DC} and I_{AC}. This prototype equipment shall be suitable for operation of the full scale magnet network excitation sources, and will be tested on the MK II model magnet power supplies. The servo will be designed for the following accuracies:-

(a) I_{DC} and I_{AC} servo loops to 0.01% over a period of several hours

(b) I_{DC} and I_{AC} sampling to better than 0.01% (aim at 0.001% over a similar period).

(c) I_{DC} and I_{AC} reference sources to provide adjustment from 100% down to 0.01%, preferably by motorised coarse control (to limit surge currents when changing excitation levels and at "switch-on") with fine hand control. The reference sources to have a long term accuracy of better than 0.01% (aim at 0.001%).

(d) Ignitor firing by phase control to an accuracy of $\pm 0.1°$ and a jitter of 1 μ sec. or less.

The principle disturbances to be attenuated will be those originating in the "mains"; variations in the magnet resonant network will be temperature dependant; limited in amplitude and having long time constants.

Two additional possible improvements in the servo performances shall also be considered and experimental experience with the MK II model magnet will show if they are necessary:-

(i) To superimpose a limited $\dot{B}_{INJ}$ error signal on both the I_{DC} and I_{AC} control loops.

(ii) To advance or retard the firing position of the ignitron in order to compensate for fast "mains" disturbances.

[1] See also EL/TM-1 "Some notes on the analysis of the pulse power supply performance" and EL/S-1 "Specification of scale-model energy storage choke" for more detailed description of the resonant magnet network and its power supplies.

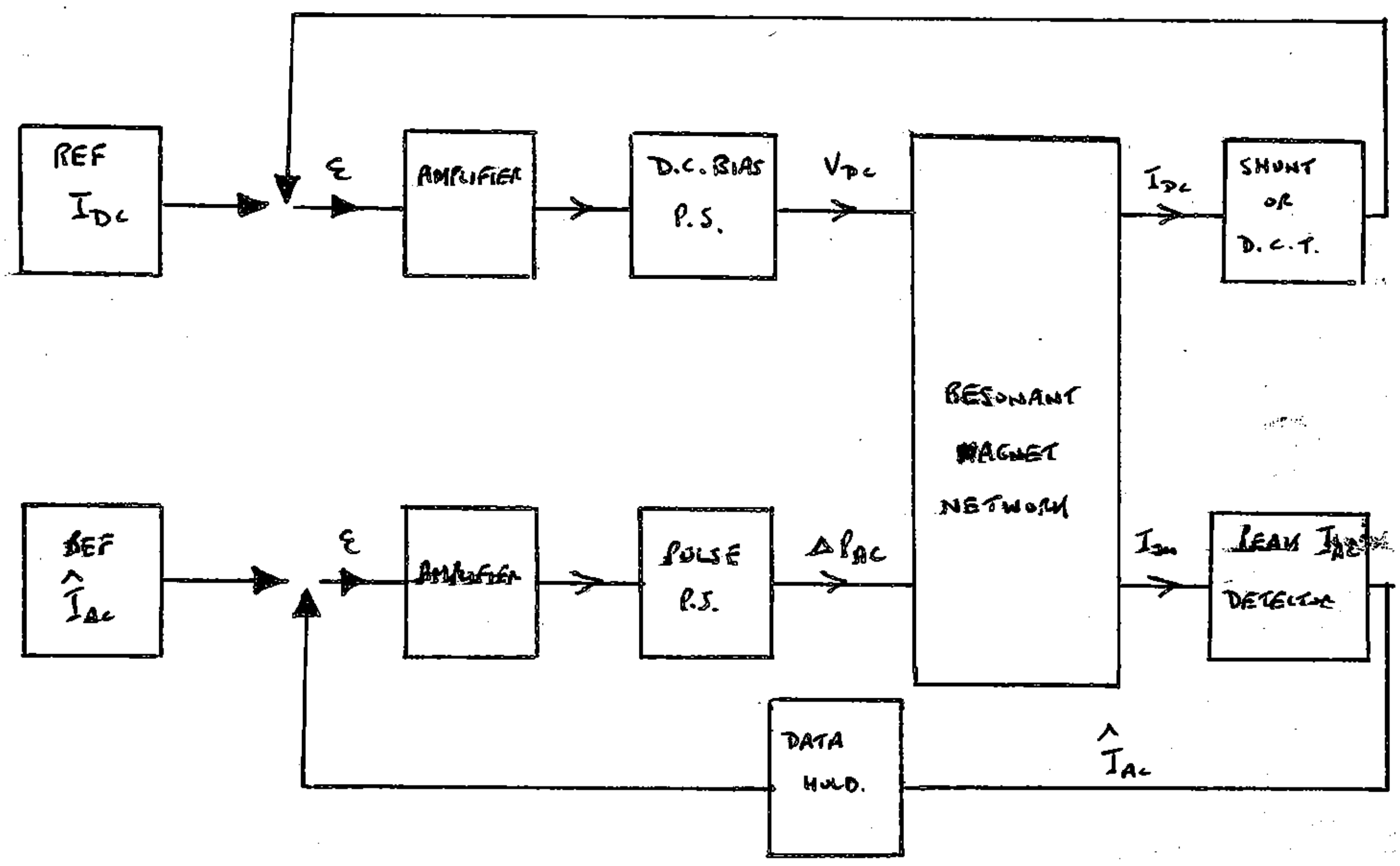


FIG 1 I_{DC} AND $\hat{I}_{AC}$ CONTROL

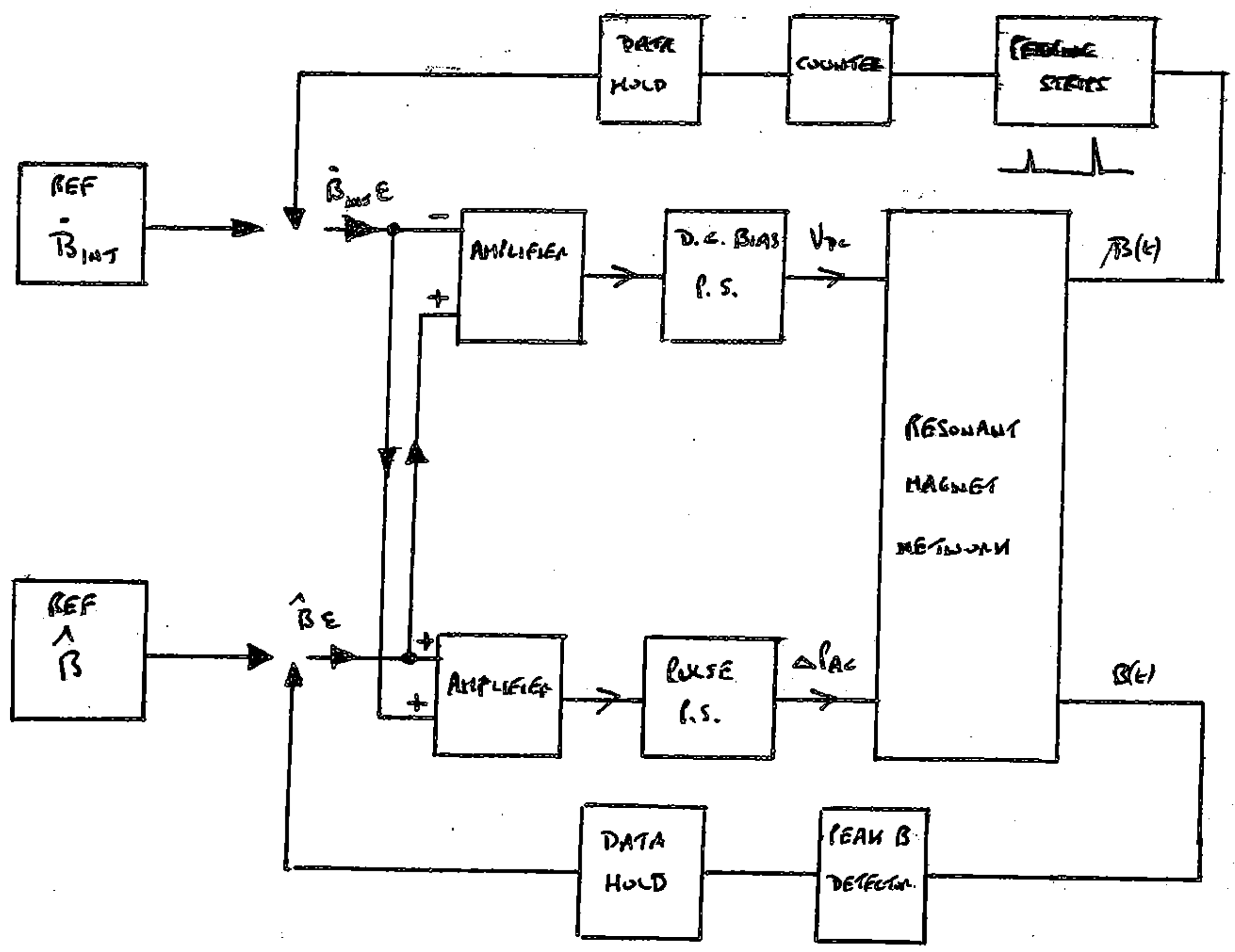


FIG 2 $\dot{B}_{INT}$ AND $\hat{B}$ CONTROL

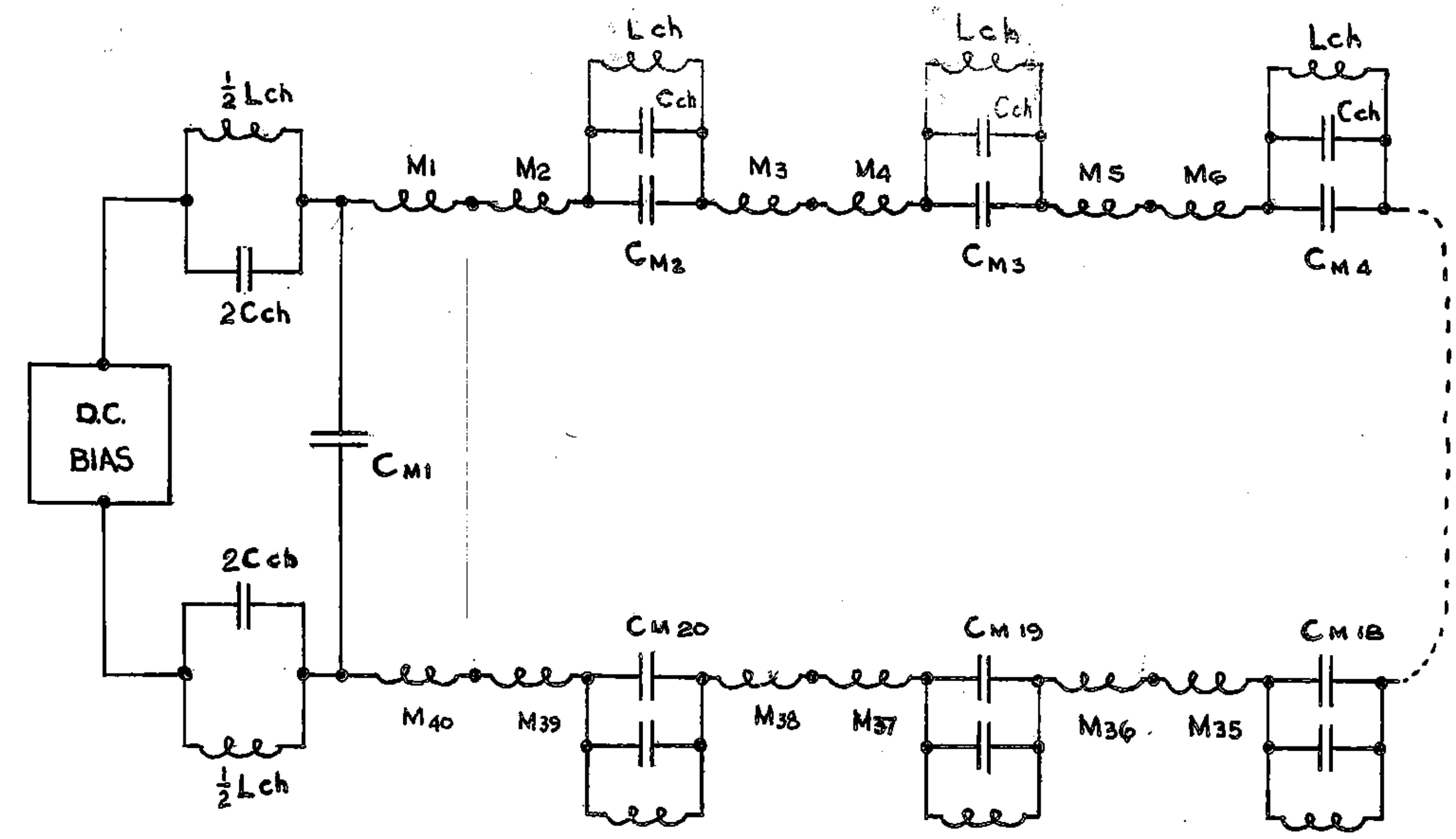


FIG. 3. RESONANT MAGNET NETWORK AS SEEN BY D.C. BIAS P.S.

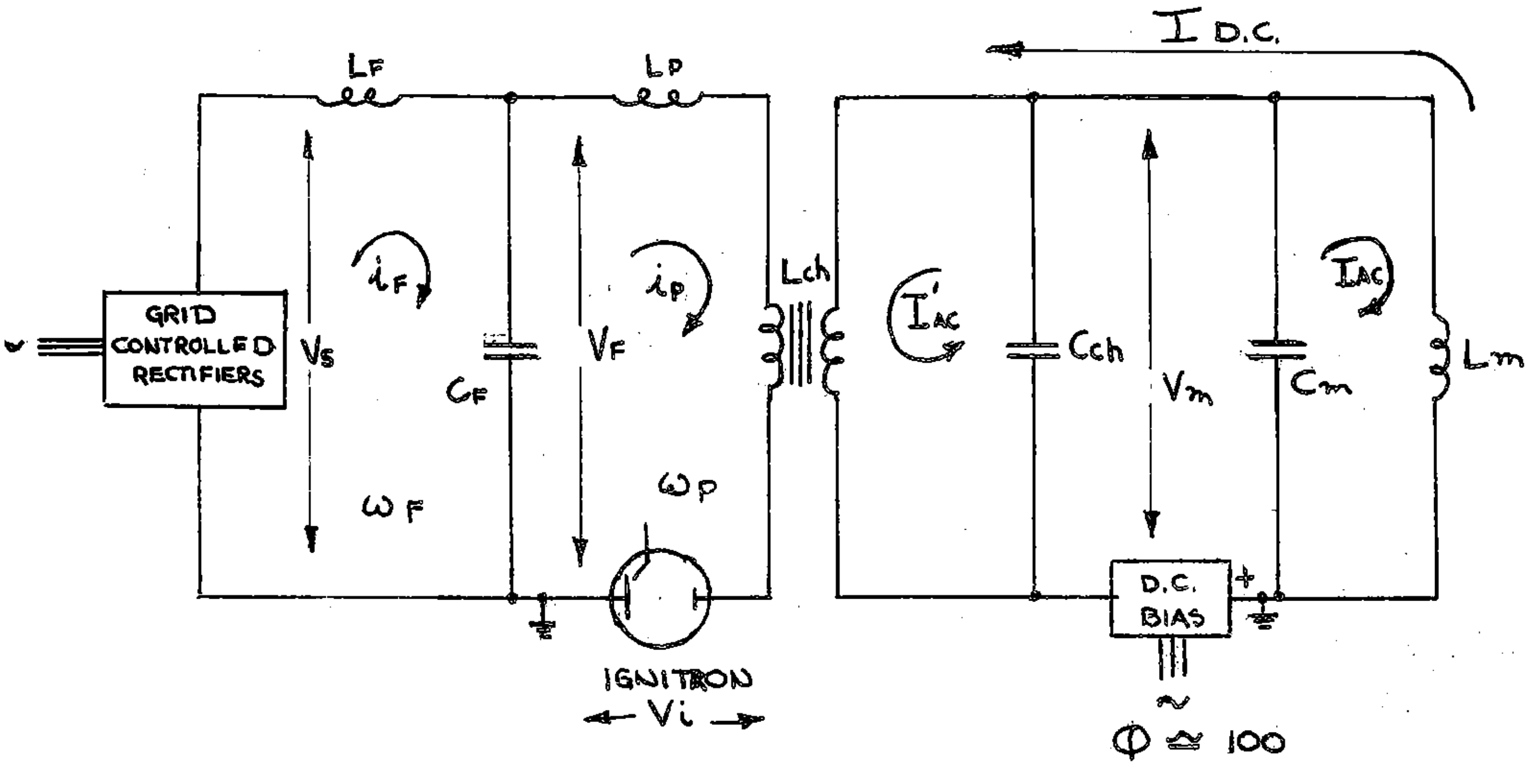
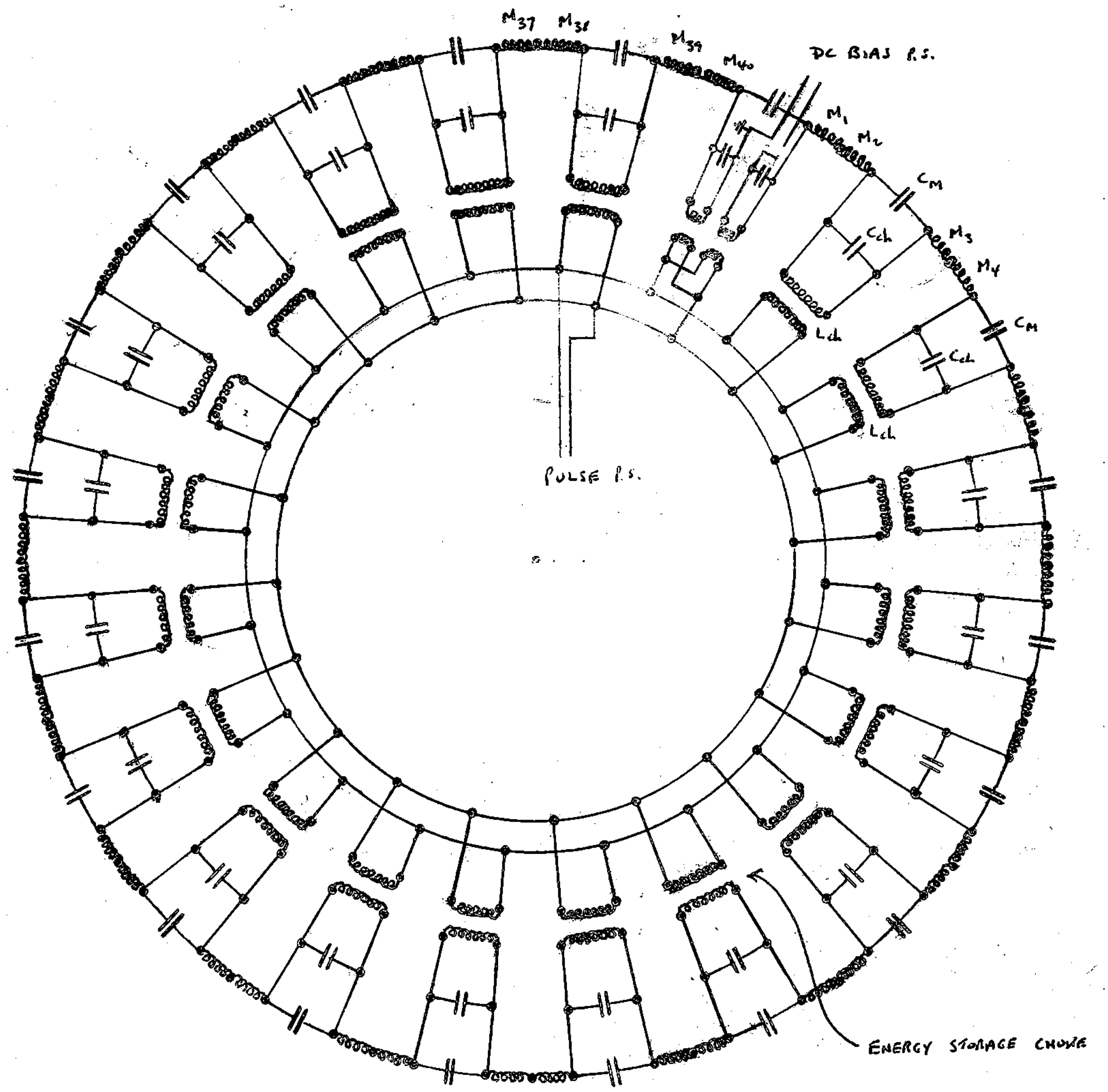


FIG. 4. PULSE POWER SUPPLY AND SIMPLIFIED MAGNET NETWORK



RESONANT MAGNET SYSTEM