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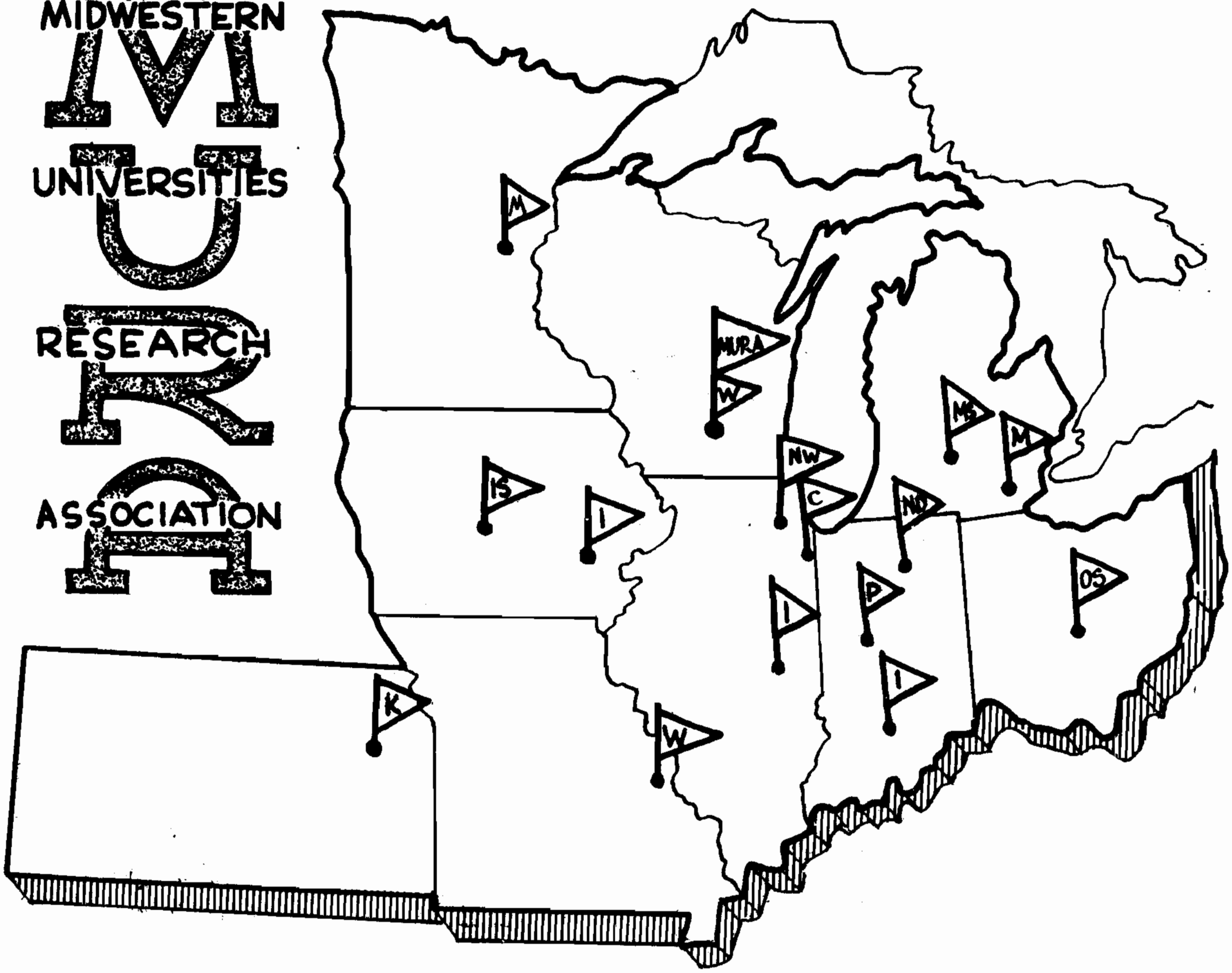

EFFECTS OF FIELD BUMPS DUE TO SLOTTED POLES

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EFFECTS OF FIELD BUMPS DUE TO SLOTTED POLES

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ABSTRACT: The effect on the orbit dynamics of the New Model of the field bumps due to burying the pole-face winding copper in slots in the poles has been investigated withthe digital computer. It is found that the vertical stability limit is affected very slightly for slots of reasonable size.

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I. INTRODUCTION

It is planned in the New Model to "bury" the backwound pole-face copper in slots in the iron surface as shown in Fig. 1.

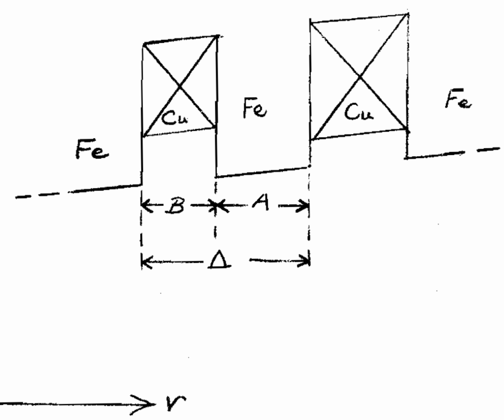

Fig. 1

This will facilitate positioning of the backwindings and will avoid the as yet unsolved problems of windings whose thickness cannot be neglected. The following is a report of investigations to determine the effect of these slots on orbit dynamics.

II. METHODS

A. The Magnetostatic Problem

The magnetostatic potential at the iron surface varies with radius in a stepwise manner as shown in Fig. 2 rather than smoothly as r^{k+1}.

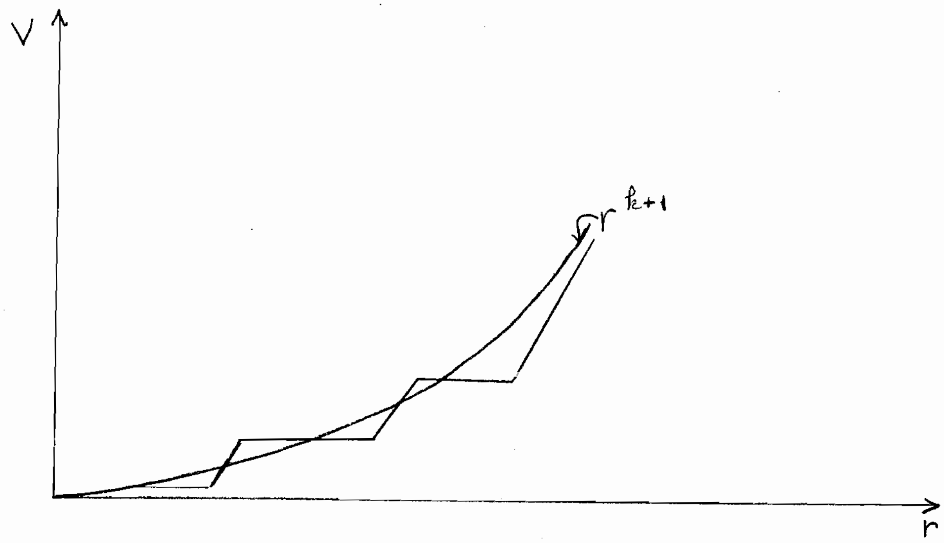

Fig. 2

The maximum deviation of the actual from the ideal potential is given by

$$\Delta V \cong \frac{1}{2} \frac{A}{\Delta}(H_{tan}\Delta) = \frac{1}{2} A H_{tan} , \tag{1}$$

where H $_{tan}$ is the tangential component of the field at the surface. The deviation is roughly sawtooth in form with amplitude increasing as H_{tan} (i.e., as r^k). This sawtooth may be approximated by a sinusoidal variation

$$\Delta V = -\frac{1}{2} A H_{tan} \sin\left(\frac{2\pi r}{\Delta} + \phi\right) . \tag{2}$$

Higher frequency components which must be added to this to give a sawtooth damp rapidly with distance from the pole face and have little effect on dynamics. Using (2) for the error potential at the pole face, the error potential everywhere is approximately

$$\Delta V = -\frac{1}{2} A H_{tan} \sin\left(\frac{2\pi r}{\Delta} + \phi\right) \frac{\sinh\left(\frac{2\pi z}{\Delta}\right)}{\sinh\left(\frac{2\pi z_p}{\Delta}\right)} , \tag{3}$$

where z is the distance above the median plane and z_p the pole height (half-gap). This formula neglects the effects of the third (θ) dimension. The validity of this two-dimensional approximation has been verified using the "Forocyl" program of the MURA IBM 704 digital computer. With N = 0 and $\frac{1}{w} = \frac{2\pi r_1}{\Delta}$ the field on a radial section through the center of a pole can be calculated. Results show that the two-dimensional approximation is quite accurate for the present purpose.

With $\Delta \sim 2$ cm and $z_p \cong 5$ cm, the arguments of the hyperbolic functions in (3) are large whenever the bump has an appreciable magnitude and therefore these functions may be replaced by exponentials. In terms of the variables

$$\left\{ \begin{aligned} x &= \frac{r - r_1}{r_1} \\ y &= \frac{z}{r_1} \\ \lambda &= \frac{\Delta}{r_1}, \end{aligned} \right. \tag{4}$$

where r_1 is a reference radius and in terms of the scaled fields h (as used in the "Formesh" program), the "bump" fields are

$$\begin{aligned} \Delta h_z &= \frac{2\pi}{r_1 \lambda} \frac{A h_{tan}}{2} \sin\left(\frac{2\pi x}{\lambda} + \psi\right) \exp\left[\frac{2\pi}{\lambda}(|y| - y_p)\right] \\ \Delta h_r &= \pm \frac{2\pi}{r_1 \lambda} \frac{A h_{tan}}{2} \cos\left(\frac{2\pi x}{\lambda} + \psi\right) \exp\left[\frac{2\pi}{\lambda}(|y| - y_p)\right], \end{aligned} \tag{5}$$

where ψ describes the phase of the slots relative to the reference circle. The sign of Δh_r is + for $y > 0$, - for $y < 0$.

These error fields are inserted in the "Stumblebump" program.

B. The Stumblebump Program

This program allows an error in the field of the form

$$g(y)\left\{\begin{matrix}\cos\\ \sin\end{matrix}\right\}\alpha_1 x + f(y)\left\{\begin{matrix}\cos\\ \sin\end{matrix}\right\}\alpha_2 x. \qquad (6)$$

g (y) and f (y) are polynomials of third degree. This function may also be set equal to zero for $|y| < y_m$.

All of the dynamics calculations have been carried out for an equilibrium orbit with $r_1 = 125$ cm, which is approximately the minimum radius of the New Model. The effects of the slots decreases with increasing radius even if the slots scale because of the exponential drop-off of the bump field with distance from the pole. (For scaling slots and constant y, the ratio of bump field to unperturbed field is independent of radius) All of the calculations have assumed also $A = B = \frac{1}{2}\Delta$.

A major difficulty in using the Stumblebumps program arises from the need to approximate the exponentials of (5) by a polynomial of third degree, as in (6). For Δh_z, only constant and quadratic terms in y are available, while for Δh_r there are only linear and cubic terms. The coefficients of the approximating polynomials have been obtained by matching the polynomials and exponentials at two points. This fit grossly underestimates the bump outside the interval bounded by these points, but overestimates within this interval.

Some preliminary work was done with $\Delta = 2$ cm. In this case the functions were matched at $y = 0.02$ and $y = 0.025$. The bump was set equal to zero for $|y| < 0.02$. (In all cases $y_p = 0.04$)

For $\Delta = 3$ cm, the matching was done at $y = 0.01$, where the peak value of the bump field is about 0.07% of the unperturbed field at $y = 0.025$, where the peak value of the bump field is about 3% of the unperturbed field. Between these points the polynomials become as much as three times the exponentials (at $|y| < 0.016$).

For $\Delta = 4$ cm, several matchings were used. For one way operation (operating point ϵ''), the stability limit is $|y| \cong 0.022$. The matching was done for this case at $y = 0.01$ and $y = 0.03$. At intermediate points this bump is too large by a factor three. For two way operation (ϵ), the stability limit is $|y| \cong 0.013$. The matching was done for this case at $y = 0.008$ and $y = 0.016$. This overestimates the bump by a maximum of 50%.

In each case the bump was present in the negative magnets only, due to the limitations of the Stumblebumps program.

III. RESULTS

In each case a search was made with decreasing values of y_o (initial vertical amplitude) and with $p_{x_o} = p_{y_o} = 0$, $x_o = x_f$ (radial motion on the equilibrium orbit). This search was done for $\psi = 0$, $\pi/2$, π, $3\pi/2$ in (5). For $\Delta = 2$ cm, no difference could be found between the unperturbed motion and the motion with bump. The following tables summarizes the $\Delta = 3$ cm and Δ = 4 cm data, giving the y_o for stability with the choice of ψ giving the smallest y_o.

	Unperturbed	Δ = 3 cm	Δ = 4 cm
ϵ	0.0135	0.0130	
ϵ'	0.022	0.020	
ϵ''	0.022	0.022	0.016

(ϵ' is a one way operating point roughly midway between ϵ and ϵ'')

In all cases the reduced y_o for stability was due to the bump being presented in just one of the phases (not the same phase for all three operating points), while for other phases the stability was ofttimes improved.