# CALCULATION OF MOTOR SPEED OF THE SIEMENS M.G. SET DURING A PULSE 

A. Feltman

July 1984

# Collider Accelerator Department <br> Brookhaven National Laboratory 

## U.S. Department of Energy <br> USDOE Office of Science (SC)

[^0]
## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

AGS Division Technical Note
No. 204

CALCULATION OF MOTOR SPEED OF THE SIEMENS M.G. SET DURING A PULSE
A. Feltman

July 31, 1984

The motor generator system has been designed so that under normal circumstances the motor speed over the duration of an AGS magnet pulse varies by less than $\pm 2 \%$. This is with a motor power input variation of less than $\pm 200 \mathrm{KW}$. Considering that the main magnet power supply output goes from +70 MW to -70 MW during the pulse, these power swings must be absorbed by the rotational energy of the MG set. This has been accomplished by designing the generator rotor with a large radius resulting in a large moment of inertia. At 1200 RPM , the stored energy is 310 MJ .

The motor speed at any time during a pulse can be determined by considering the electrical and mechanical relationships

$$
\text { 1) } P_{i n}=J W \frac{\partial W}{d t}+P_{W}+P_{E}
$$

where

$$
\begin{aligned}
\mathrm{P}_{\text {in }} & =\text { power into the motor } \\
\mathrm{J} & =\mathrm{MG} \text { set moment of inertia }\left[40\left(10^{3}\right) \mathrm{kg} \mathrm{M}\right. \\
\mathrm{W} & =\text { rotational speed in radians } / \mathrm{sec} \\
\mathrm{P}_{\mathrm{W}} & =\text { windage and bearing losses }(850 \mathrm{KW}) \\
\mathrm{P}_{\mathrm{E}} & =\text { electrical power }
\end{aligned}
$$

Three types of elements contribute to the electrical power term $\left(P_{E}\right)$. They are resistance ( $P_{R}$ ), inductance ( $P_{L}$ ) and arc drop ( $P_{A}$ ). Let us discuss these items a little further.

The arc drop term is attributed to the arc drop across the excitrons. For each excitron this is equivalent to a 16 volt battery in series $13 \mathrm{~m} \Omega$. For the whole power supply, this is equivalent to 128 volts in series with $50 \mathrm{~m} \Omega$. For convenience, this $50 \mathrm{~m} \Omega$ and other power supply resistances are lumped in with the load resistance of $0.25 \Omega$ to comprise a total resistance of $0.3 \Omega_{0}$ This $0.3 \Omega$ will be used for the determination of the " $\mathrm{P}_{\mathrm{R}}$ " term. This 128 volts will be used for the "P ${ }^{A}$ " term.

Now, the inductive term is something somewhat special. The main reason is that the prime source of the system inductance is that of the magnet whose inductance varies with the current. This variation is from 0.5 to 0.8 Henries. The main value used in this note will be 0.7 H . This includes also the reactive drop in the transformer connections, etc. It should also be pointed out that the " $P_{\text {" }}$ " term can be either positive or negative depending upon whether the current is increasing or decreasing.

In light of these comments, we can then conclude that

$$
\text { 2) } W \frac{\partial W}{\partial t}=\frac{\left(P_{\text {in }}-P_{W}\right)}{J}-\frac{\left(P_{E}+P_{R}+P_{L}\right)}{J}
$$

Integrating both sides from 0 to t yields
3) $W^{2}-W_{o}^{2}=\left(\frac{P_{i n}-P_{W}}{J / 2}\right) t-\frac{1}{J / 2} \int_{0}^{t}\left(P_{E}+P_{R}+P_{L}\right) d t$

$$
\text { 4) } W^{2}=W_{o}^{2}+\left(\frac{P_{i n}-P_{W}}{J / 2}\right)_{t}-\frac{I}{J / 2} \int_{0}^{t}\left(E_{E} I+R I^{2}+L I \frac{d I}{d t}\right) d t
$$

## If "I" has form

$$
\text { 5) } I=I_{o}+\alpha t
$$

then,

$$
\text { 6) } \frac{\mathrm{dI}}{\mathrm{dt}}=\alpha
$$

and then

$$
\text { 7) } \begin{gathered}
W^{2}=W_{o}^{2}+\left(\frac{P_{i n}^{-P} W}{J / 2}\right) t-\frac{1}{J / 2} \int_{o}^{t}\left[\left(E I_{o}+\alpha L I_{o}+R I_{o}^{2}\right)+\right. \\
\\
\left.\left(\alpha E_{E}+L \alpha^{2}+2 \alpha R I_{o}\right) t+\alpha^{2} R t^{2}\right] d t
\end{gathered}
$$

and
8) $W^{2}=W_{o}^{2}+\left(\frac{P_{i n}-P_{W}}{J / 2}\right) t-\left(\frac{E_{E} I_{o}+L \alpha I_{o}+R I_{o}^{2}}{J / 2}\right) t$

$$
-\left(\frac{E_{E} \alpha+2 R \alpha I_{o}+\alpha^{2} L}{2(J / 2)}\right) t^{2}-\frac{\alpha^{2} R t^{3}}{3(J / 2)}
$$

During a pulse, four current segements can be identified. They are: injection porch, rectify, flattop, and invert. The current characteristics during each of these intervals are as follows:

Injection Porch
9) $I_{I P}=\left.2956 \mathrm{t}\right|_{0} ^{\mathrm{t} 0.11 \mathrm{sec}}$

Rectify

$$
\text { 10) } I_{R}=325.16+10,\left.500 t\right|_{0} ^{t_{R}}
$$

## Flattop

$$
\text { 11) } I_{F}=I_{F} \text { (constant) }
$$

Invert

$$
\text { 12) } I_{I}=I_{F}-11,\left.250 t\right|_{0} ^{t_{I}=0}
$$

Therefore, during the injection porch,
13) $W^{2}=W_{o}^{2}+\left(\frac{{ }_{i n}-0.85\left(10^{6}\right)}{2\left(10^{4}\right)}\right) t-162.4 t^{2}-43.69 t^{3}$

Where $W_{o}$ is approximately $1.5 \%$ above the synchronous (rotational) speed. The synchronous speed is 1200 RPM or 125.66 radians per second. $1.5 \%$ above this is about 128 radians per second. $W_{o}^{2}$ is then 16,384 .

During rectify we get
14) $W_{R}^{2}=W_{o R}^{2}+\left(\frac{P_{i n}-0.85\left(10^{6}\right)}{2\left(10^{4}\right)}\right) t_{R}-121 t_{R}-2014 t_{R}^{2}-551 t_{R}^{3}$

Where $t_{R}$ is reckoned from the end of the front porch ( $t-0.11$ ) and $W_{o R}$ is the speed at the end of the front porch.

During flattop
15) $W_{F}^{2}=W_{o F}^{2}+\left(\frac{P_{i n}-0.85\left(10^{6}\right)}{2\left(10^{4}\right)}\right) t_{F}-\left(\frac{128 \mathrm{I}_{\mathrm{FO}}+0.3 \mathrm{I}_{\mathrm{FO}}^{2}}{2\left(10^{4}\right)}\right)_{\mathrm{t}}$

Where $t_{F}$ is reckoned from the beginning of flattop and $I_{\text {Fo }}$ is the current at the beginning of flattop.

For invert, the following relationship exists
16) $W_{I}^{2}=W_{o I}^{2}+\left(\frac{P_{i n}-0.85\left(10^{6}\right)}{2\left(10^{4}\right)}\right) t_{1}+\left(\frac{7747 I_{o l}-0.3 I_{o l}^{2}}{2\left(10^{4}\right)}\right) t_{1}$

$$
-\left(2179-0.1688 I_{o 1}\right) t_{1}^{2}-632.8 t_{1}^{3}
$$

$W_{o l}$ is the speed at beginning of invert at $t_{1}$ is reckoned from beginning of invert.

Assuming an M.G. set initial speed of 128 radians per second, the speed as a functin of time has been calculated over the duration of a typical $28 \mathrm{GeV} / \mathrm{c}$ AGS magnet current pulse. This corresponds to a current of 5050 amperes. This was done for a 1.0 second and a 2.0 second flattop. Two sets of calculations were made; one set for a motor net power input of four megawatts, the other for seven.

The results of these calculations are tabulated on the following pages. A plot is also included.
mvh

Distribution: Dept. S\&P
Siemens Techs

## IMSECTION PORCH

## $P_{1 H}+D_{\omega}=4 \mathrm{~m} \mathrm{\omega} \quad .7 \mathrm{~m} \mathrm{\omega}$

|  | $\begin{array}{r} 8201 \\ 28,045605 \end{array}$ | $\begin{gathered} \text { हEG } \\ \text { Rnpe } \end{gathered}$ |
| :---: | :---: | :---: |
| $0 . \square$ | 0.0e | SEC |
| 59. | 5.12 | Mffe |
| Me. HEQ | 2e.09708E | Rens |
| 0. 09 | 0.08 | SEC |
| ce. 6 e | 88. 68 | MHPS |
| 12s, gedesey | 12 E .0404387 | RHIS |
| 0.84 | 0.04 | SEC |
| 118.24 | 118.24 | Gmpe |
| 128. पुपद05 | ' 2 e .053605 | RADS |
| 0.05 | 0.05 | SEC |
| $147=8$ | 147 ${ }^{1} 8$ | Fhre |
| 12e. 19745 | 129.0667347 | Fhns |
|  |  |  |
| 0.06 | 0.06 | sEc |
| LP: ${ }^{\text {a }}$ | 177=36 | 日fps |


| 0.07 | 0.07 | SEC |
| :---: | :---: | :---: |
| 206.92 | 206.92 | PuPs |
| 128. 日tsma | 28.0925027 | Rnte |
| П. - | 0. 08 | SEC |
| 296.48 | 236. 48 | Ampe |
| 128.05699. | 98. 105184 | Raps |
| 0.8 | 0.09 | SEC |
| 266. 04 | 266.04 | ntrs |
| 198.065039 | 17729 | Ehas |


| 0.1 | 0.1 | seg |
| :---: | :---: | :---: |
| 295. | 2956 | Alfs |
| 12e.0psen | 28. isulse | Ents |
| O.: | 0. 11 | SEC |
| Se5. | 925.16 | Pmpe |
| me.07601\% | Se. 1424089 | Enis |

D. $\quad 0.12$ SEC
354.

354,72
12e. Geq e.
$1945=998$


| -Pw | 4Mw |
| :---: | :---: |
| $\begin{array}{r} 9696 \\ 127=59299 \end{array}$ |  |
|  |  |
| 4, 0,27 |  |
| $\cdots$ | 80.5 |
| - 276 EDCta |  |
| प्र, |  |
|  |  |
|  |  |
| प47 50976 |  |
|  |  |
| , ${ }^{\text {a }}$ |  |
| $\bigcirc$ |  |
| $\cdots 27=4854$ |  |
| $0.3$ |  |
|  |  |
| 34516$127=49974$ |  |
|  |  |
|  |  |
|  |  |
| 959, |  |
| 127, 3 BL |  |
| \% " |  |
| - 685 B |  |
|  |  |
| $127=30555$ |  |


| $272496$ |
| :---: |
|  |  |
|  |  |

0,34 6g9f 127.12652 0.35
$49-19962$
0.36
$410 \mathrm{E}, \mathrm{E}$ $127=072420$
$74 \omega$
5. 26

3日f 127 , $\quad 27$ 316, 127,6914


76E5, 6 $127=54121$ 10
1279
129
T. 34 969.16 $127=456 \operatorname{cog}^{7}$
0. 35 400.6 129 4104 a
0. 36
$4105=16$ $127=3550317$
$\square$


## $4 m \omega$

7 mm
PIH-PW
4mw
7an
0.09 125.39753
0.13 126. 31372
0. 23 $126,2 \cos 9$
0.3 B 126. 1494867
10.49
126.06826
0.53 125.9730257
0.69 125. 8 mpr
0.73 125.80es316

1 0.89 125.716697
0.95 125.63405
$125,54=09$
1.13
$125+460468$
0.89 126. 5498516
0.79 1\%6.574943

125,5456554
0.93 126.523136

i. 1 c
120.472421 m

SEC FADS
seg $\operatorname{seg}$ RADS sEC Rnis
$\operatorname{sEC}$ Rhis
-25, 34568,14646766
 125.266542 126.4211096

1. 43 $125.2090698 \quad 126,394458$
2. 53
3. 58 125.117268 126369767
4. 69 $125,031524 \quad 126,341023$
1.79 $124=943636$
i. 89 124.859438
1.83 $124=772637$
2.03
$124=6671246$
$\qquad$
126.2413525
i. 99 126. 26747
2.0\%
i. 73 i2g 31842g
5. 89 12g. 2gerare
sec EADS
geg EnDS

 ? sed
EEG ,


$4 m \omega$
0.01
6. 66 $124=75769$
0.02
$4825=16$ $124=8271434$
0.03
4712.66 124.895468

0,94
4600. 16 124596636
0.05 $4487=65$ 125. पद865:
D. 0
495.16 125.0595013
0.07

426268 1251571692
0. 08 4150.16 125219627
0.59
4037.66

125 280sgot
i. 1
9925.16

125 3400091
D. 11
3812.66 125.597

## $7 m \omega$

0.01
4997.66 126.3169

12 4eg5176
0.05 472.66 126.464927
0. 04
4500.16

465 571917
9. 95
4487.6g

Les 60821e
0.06
497516 126. 678201
0.07
4262.65 $126=7470534$
0. प8

415 i 126.814646
0.99
4087. 68
O. 1
$3 \operatorname{en} 16$ 12694629
0. 11
3012.66 $127=0101759$

## $4 m \omega$

## 7mW

sed nypg Rang
sec Rmpg

SEC HAF RADS
sEC RHES

Rhas

SEC
Amp
Ents
BEG
Rene
SEC
RnPs
EEG
RATG

REG
SE
MuFs
Rhis
EEC
PMPS
Rats
4mw gmw

0.19

0.13
$127=1349481$
0.14 947516
0.15

SEC RHPE

SEC Paps

SEC
GHPs

SEC
mes Rhis

SEC
murs RADS

SE BHPS RHIS

SE GmPs Ente
sec MFP RADS
$4 m \omega \quad 74 \omega$

|  | 0.23 | SEC |
| :---: | :---: | :---: |
| 0.29 | 2462.65 | nmps |
| 245266 | 127.671241 | RhDS |
| 196. 0 ¢Ts |  |  |
|  | D. 24 | SEC |
| 0.24 | 2 en 16 | GIFS |
| 2950.16 | 127.2898 | Rate |
| 126.045eses |  |  |
|  | 025 | C |
| 0.25 | 4 $2297=6$ | Gups |
| 2237.66 | $127=769242$ | Rhns |
| 12, neseber |  |  |
|  | 0.26 | SEC |
| 0.26 | 212516 | ntrs |
| 212516 | -127813296 | RATE |
| S. izseget |  |  |
|  | 0.27 | 5 EC |
| 0.27 | 2026 | GMPS |
| 2012.66 | 127.85848 | Rens |
| 126. 161055 | $12, \operatorname{cosec} 4$ |  |
|  | 0.23 | sec |
| 0.28 | i900. 16 | nupe |
| 1900. 16 | 127.8969046 | Rats |
| 126.1967438 |  |  |
|  | 0.29 | SEC |
| 0.29 | $1787=66$ | Emps |
| 1787:66 | 127=965ise | Rats |
| 126.2309507 |  |  |

0.3
1675.16 126. 2696e2
0.31
1562.66 126.296645
0.32
1450. 16

0. 33
1337. 66 126. 35266
D. 3
1562.6 128. 011297
0.32
1450. 16 128. 046485
0.3 e
$1397=66$ 128. 06005 e
0.34 1229.16

## 4mw

0.35
112.66 12s. 40450s
0.36

1000,16
12 e .427507
0.37
887. 66

126 4496047
I. 38
$775 \cdot \operatorname{re}$
12g 46कहा4
0.39
62. 66
126.48475
0.4
550.16
126.5054657
0.41
$497 \cdot 66$ 126. 5608048
0.42
925. 16

126534493
0.43
212.66

125 546474
0.44
100. 16
126.55676
0.45
$-12=34$
i2c. 565 B
$7 m W$
0.35
1112.66 128.142686
0.36 1000. 16 128.171666
0.37
887. 86
128. 199074
0.96

77516
128.224897
U. 39
662. 66

12 E .24112
O. 4
550.16
ige 271715
0.41
$437=66$
128. 2926891
0. 42

32516 128. 320201
0.43
212.66
128. 32969
0.44
100. 16 128.3456965 RHES

SEC RHPS ERIS
$\operatorname{sE}$
AmPs
$128=121459$


Injection Porch


## Rectify




$$
I=I_{F}-\frac{(300)(7.5)}{0.2}=I_{F}-11,250 t
$$

FIGURE 3


[^0]:    Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

