MPS/ED - Note 68-5
18.6.1968

POWER SUPPLIES IN U.S. LABORATORIES

VISIT IN THE UNITED STATES FROM MAY 10th TO 31st 1968

by R. Mosig

Laboratories visited

Brookhaven National Laboratory (BNL)

Argonne National Laboratory (ANL)

National Accelerator Laboratory (NAL)

Lawrence Radiation Laboratory, Berkeley Calif. (LRL)

Stanford Linear Accelerator (SLAC)

PS/6608

C O N T E N T S

1. GENERAL

The intention of my visit to the different laboratories in the United States was mainly to gather some information about the existing power supplies in use and the trend in computer controlled beam transport. The information at CERN in this field was sparse and K.H. Reich's report+ written in 1963 reported only "in passing" about this subject.

In view of a probably necessary converter set for the Booster-Supply I tried also to get some information about their running experience.

All the veast impressions properly described would give a too bulky report; therefore telegramme-style notes are preferred, concentrating on the important points. Readers interested in more detailed information are therefore asked to contact me.

Accelerator people seen at :

BNL
Dr. K. Green, Accelerator Department,
K. Lasky, Magnets, main power supply,
R. Adams, Conversion AGS, Power equipment,
J.G. Cottingham, Controls, Electronics,
A. Soukas, Power Supplies (Ejection Beam transp.),
E. Kessler, " " " " " ,
F.W. Spinner, Transistor Cooling devices.

ANL
F. Manson, Deputy of Dr. Martin (absent),
G.F. Sellers, Main Magnet Power Supply,
A. Visser, Beam Transport,
D. Nordby, Beam Layout,
Dr. A. Rohrmayer, Pulsed power supplies directly connected to the mains,
G. McGhee, Computer controlled proton beam.

NAL
Prof. Wilson, Head of NAL Research Group,
R. Cassel, Design of Main Magnet Power Supply,
F.C. Shoemaker, Magnet design
present address : 1301 West 22nd Street, Oakbrook Ill.

LRL
E.C. Hartwig, Main Magnet Power supply beam transport,
T. Jackson, Beam transp. power supplies,
D. Evans, Computer controlled beam transport.

SLAC
C.A. ("Slim") Harris, Beam transport power supplies,
F.L. Harris, Beam Magnet and Operation,
M.M. Berndt, Beam transport supplies,
D. Fryberger, Coordinator for Experimental Equipment.

\+ K.H. Reich, Status of some U.S. accelerators, summer 1963, MPS/Int. DL 63-16

2. MAIN MAGNET POWER SUPPLIES

2.1. Cycle

BNL-AGS with new Motor generator set will be operated for some time with 50 MeV injection (until 200 MeV Linac is finished). Fig. 1 shows cycle for 50 MeV and Fig. 2 for 200 MeV injection. Preliminary tests showed, that approximately 2 times slower changeover from $\dot{B} = 0$ to full rise against the $5^{0}/o$ loss curve gives particle loss not essentially better than $5^{0}/o$ but practically independent of $\dot{B} = f(t)$.

ANL-ZGS runs with 2,6 sec. repetition rate with 10 kV rise, 10 kA peak full energy (12,5 GeV).

NAL cycle (Fig. 3) shows similar wave-forms to the CERN Booster, due to same rise time - time constant ratio (1,6 + 1,7). More details see 7. k).

LRL-Bevatron with 16 kV rise/1,5 kV flat top voltage and 6 kA peak current (1,8 sec. rise and fall; 0,5 sec flat top) is similar to the AGS, however with special flat top conditions (see 2.3.).

SLAC pulses 360 times/sec., within approx. 1 s electrons and positions can be accelerated alternatively (Fig. 4).

2.2. Rotating Machines

The BNL-AGS people are concentrated on the "conversion" (new MG set and mercury arc rectifiers giving 12 kV rise voltage). Excavation for MG set inside the ring finished. Attitude towards rotating machines : no prevailing disadvantages if mechanically correctly designed, independence from the mains judged as a great advantage (see 3.2. and 5.1.).

The ANL-ZGS runs at present for the 12,5 GeV programme with approx. 110 MW peak (10 kV rise 10 kA flat top). It is envisaged to operate the ZGS directly from the mains with reduced power in case of MG set failures (details see 3.2.).

NAL Oakbrook plans a static Main power supply very similar to our Booster scheme with an active power compensator (induction motor generator with flywheel). Details under 3.1.

The LRL Bevatron supply does not permit a symmetrical firing angle control during flat top (resonances) another power circuit connection will be tried out in the near future.

2.3. Rectifiers

The Ignitrons or Exitrons (at ANL-ZGS) have in all laboratories about the same arc-back rate : 1 per shift (3 per day). This is considered as normal. Since ZGS rectifier type will not be manufactured any more by Allis-Chalmers, overhauling process is done by ZGS people with success. Trouble was reported with DC and anode aluminium cables (hot spots).

To equip large pulsed supplies with thyristors instead of mercury arc power rectifiers is generally considered with some scepticism. Exception : NAL high voltage (25 kV) moderate peak current (2400 A) and ring dimensions resulted in 24 separate thyristor supplies (with magnet sections series connected).

2.4. DC Filters

This subject was discussed in detail at Brookhaven (see 7. a), b) and c)). Passive filter design is similar to CERN main magnet power supply but seems to have higher overshoot (lower $R/\omega_0 L$). Frequency response (see 7. a)) asks for more care with subharmonics,

This problem, caused essentially by the imperfections of the grid control systems, will be attacked by means of a special subharmonics compensation system (Details in 5.1.).

The task for the AGS filter is facilitated by the use of a separate flat top supply (less raw ripple).

2.5. Rotor circuit of the driving motor

The mean speed regulation with the present MG set at BNL-AGS is performed with an electronic tube in parallel to the Rotor resistor. It is for 3°/o slip variation an interesting solution (Fig. 5).

ANL-ZGS uses contactor operated resistors in the rotor circuit adjusted according to the slip obtained during the foregoing pulse. No complaints for the consequent jitter in rise time or flat top current obtained.

The LRL-Bevatron is supplied by two MG sets running independently. Tests are planned to synchronize the two sets by parallel connection of the rotor circuits over resistances. For the time being no complaints about the inevitable beat frequency content in the total magnet voltage.

3. COMMENTS ON CERN BOOSTER POWER SUPPLY PROPOSALS

3.1. Power circuit

BNL-AGS reaction initially sceptic, after discussion (with Dr. Green and F.G. Cottingham) "feasible". Main argument against supplies without MG set : mains influence affecting pulse reproducibility. Judgement seemed to be influenced by the supposed NAL ideas to obtain high order stability with static supplies directly connected to the mains (It turned out later at Oakbrook that flat top current stability of only 5×10^{-4} is sufficient). With A. Rohrmayer (ANL) the main circuit was briefly discussed, the emphasis was put on the mains perturbation caused by pulsed supplies (Details, see 3.2.).

It was a surprise to learn that R. Cassel (NAL) intends to use the same rectifier circuit (Fig. 6) we planned for the Booster, but probably with separate transformers for each 3 phase bridge. The very precise $\pm 15^{\circ}$ phase shift becomes necessary if the primaries of each supply would be $2,5^{\circ}$ shifted consecutively. The obtained 144 phase system (see 7. j)) is in my opinion not any more beneficial (total magnet voltage ripple will mainly be determined by subharmonics caused by transformer and gate control asymmetries). The active power compensation system envisaged is similar to that investigated at CERN (Fig. 8). The lenses will have an independant circuit and be tracked by the bendings. The Q_H and Q_V are equipped with a small separate correction winding. Very interesting is the wooden tunner model with magnets lenses and bus bar system (1:1 scale). Cooling water aluminium tubes serce at the same time as bus bars.

At LRL our proposal was not discussed in detail (no comparable supply existing or planned in near future).

M.M. Berndt of LSAC ("Slim" Harris was busy with the Ling-supply modification) was interested in the rectifier circuit. SLAC had trouble with sequentially controlled rectifiers connected to the same transformer. The low mutual reactance caused thyristor misfiring if triggered with short gate pulses.

3.2. Reactive power compensation

This problem exists in all laboratories. The power factor improvement and AC-filtering of the distorted sine wave so far as DC power supplies are concerned will be discussed under 4.1.

Large pulsed supplies connected to the mains have either to be reduced in peak reactive power so that it becomes tolerable for the electricity supply authority (typical for existing main magnet supplies in case of MG set breakdowns) or especially designed for permissible voltage fluctuations (typical for new static supplies).

A.Rohrmayer (ANL) analysed the existing network for a ZGS operation directly from the mains with 50 MVA peak (reduced cycle) in case of a MG set failure. One interesting alternative should be mentioned : switched condenser bank by means of thyristors. More details in reports 7. g), j) and i).

The other typical case is the NAL poor reactive power circuit design (free-wheeling thyristors). The approx. 30 MVA r peak could be absorbed by the supply network (Chicago industrial area).

The CERN Booster solution was in general considered as a good, but only for the particular case advantageous, scheme (stand by group, reactive power corresponds to KVA rating of one group, etc.) .

The "Friedlander"-stabilizer was generally considered as too expensive particularly for smaller ratings (necessary over-dimensioning due to "back" stabilisation).

Other circuits - mainly compensators instead of stabilisers - exist only on paper.

3.3. Control and Regulation circuits

Discussed in detail with F.G. Cottingham (BNL-AGS). The "soft" changeover principle was considered as advantageous. The somewhat more complicated control circuit is largely compensated by the advantage of not operating with saturated amplifiers (better reproducibility). F.G. Cottingham proposes to close only a voltage regulation loop and to correct the current drift from pulse to pulse by means of a computer, the frequency response does not depend on the filter design in this case (it could operate even with less $R/\omega_o L$). We will accept this proposal in the belief that during the running-in period an analog circuit for the current drift correction will do the job. This kind of operation becomes particularly easy if the necessary corrections are of low frequency nature and flat top stability obtained is good and a few ms time-jitter from pulse to pulse can be tolerated.

4. BEAM TRANSPORT SUPPLIES

4.1. Power circuit and regulation

All laboratories have magnets and lenses with 40 ÷ 100 mΩ coil resistance. A typical standard magnet of BNL-AGS is the type 18D36 (1 m bending) and the type 8Q24 (60 cm lens) having a power of 285 kW and 273 kW respectively. To this standard equipment corresponds a "standard" power supply of 125 V 2400 A. Originally supplies were built with mag-amps, later with thyristors (3 phase bridge connections). The precision obtained with mag-amps at lower currents was restricted to 2×10^{-3}. Mag-amp units are in use at higher current levels with somewhat better than 10^{-3} stability. LRL uses separate transistor banks in series to improve stability. Thyristor units for DC beam transport are not combined with transistor banks (obtained stability 5×10^{-4} and better is apparently suffcient). BNL-AGS supplies are equipped with three operation modes : current,voltage (for series connection) and field (hall plates). Field stabilisation is not very often used. Most of the supplies use shunts with 5×10^{-3} absolute accuracy and 100 mV drop at nominal current.

ANL and LRL use for the regulation loop dc current transformers (4 core type) and shunts for the current reading. The LRL transductor is described in 7. 1), the basic scheme given in Fig. 9.

The reference source is often not temperature stabilized so that day to night variations come in the same order as short term stability.

Amplifiers are about the same types we have in use (Nexus, Philbrick, etc.).

Potentiometers sometimes external, sometimes equipped with small dc-motores. Typical is two-potentioneter circuit (coarse and vernier). Users do not feel inconvenience to go back to "coarse" if "vernier"-potentiometer reached its limits.

LRL makes extensive use of series connected diode power supplies. Parallel connection is also possible which makes cabling somewhat complicated (Fig. 10).

Diodes and thyristors are generally water cooled, transformers have water cooled secondary windings if rating exceeds 200 to 300 kVA.

Even with the relatively small conductor dimensions (8 x 8 mm external) no difficulties with pipe blockage were reported. The primary winding is cooled by conduction. This together with 60 cps mains gives fairly small transformers. Stray reactance of such a transformer becomes very small ($\approx$ 1°/o), consequences see 4.2.

At SLAC large transformers with complicated secondary windings for bubble chambers ($\approx$ 5 MVA) were built by Ling-Electronics according to the same principle. The 12 kV primary winding became defective after short period of operation (too high dielectric stress) and will be replaced by oil convection cooling type. CERN technique to use pyralene transformers with water heat exchangers had not yet been considered.

All supplies are arranged for stacking and some LRL-types also for side-by-side installation. The latter gives access to the different parts by the front door. Fault detection might become rather tedious (switching off is necessary, distance to live parts not sufficient to work under voltage).

Some units are equipped with polarity reversal switches. The ANL-ZGS knife type isolators are designed for motor operation. Most of the motors were disconnected due to trouble in the reversal operation.

Remarkable is the extended use of series transistor banks. The freon cooled bank at BNL-AGS for a pulsed ejection supply was equipped with 70 A Germanium transistors.

In all laboratories are quite a number of pulsed and dc-operated water-cooled transistor banks in use. All types and sizes of water-cooled heat sinks could be seen, very ingenious, but all more or less "model-shop" executions (see 7. n)), no satisfactory industrial products available on the market. Specialized manufacturers (i.e. Wakefield, Mass.) offer interesting solutions for banks of up to 50 semiconductor elements, for a few hundred transistors however parts had to be added for easier interchange ability maintenance, etc. This becomes too expensive. Dayton manufactures resistances moulded in aluminium cooling fins to be mounted on water-cooled bars (up to 50 W). In some cases emitter resistances were used (LRL) which could melt in case of transistor breakdown.

In all laboratories the "electrical" failure rate for transistors was considered as far lower than the "mechanical" one, i.e. bad soldering points, overheated fuse holders, not properly fastened transistors (consequently thermal destruction), etc. The CERN idea to parallel a few thousand transistors for the septum supply was only considered to be critical from the mechanical point of view. With a reasonable redundancy and easy interchangeability no serious trouble should be expected.

4.2. <u>AC and DC distribution, location of supplies</u>

The low voltage, high current magnet design see 4.1., together with the 480 V AC distribution system makes the installation of power supplies near the magnets very attractive. In fact all laboratories follow this scheme, either directly in the experimental halls very close to the magnets (BNL-AGS) or at least in adjacent rooms (ANL) or huts (LRL). Due to the favourable atmospheric conditions SLAC puts prefabricated huts over the supplies. In all cases no line selector was used, magnets were cabled directly with the supplies. AC was brought through huge connectors (about 150 mm diameter 3/4'' pins) to the supply. Especially in the case of LRL (series and parallel connection, see Fig. 10) changeover to a new beam layout does not seem easy, but anyway floor operators are familiar with this kind of work and don't complain.

In general the AC cables are connected to distribution boxes installed along the walls of the experimental halls (BNL AGS). There is normally no separation between the 480 V lines for power supplies and the other experimental equipment, also some electronic labs are connected to it. Under these conditions one has to pay more attention to sine wave distortions. The thyristor supplies with the low stray reactance (see 4.1.) and only 6 phase (3 phase bridge) rectification makes the distortion significant and therefore the mutual influence is sometimes a problem. This however, seems to be worsened by some grid control circuits which are sensitive to the overlapping notches (details see 5.2.).

Some sort of equipment i.e. television sets had to be improved by filtering in the line synchronisation. No laboratory smoothed the line voltage by harmonic filters. The reason for this might be that the power factor improvement is solved by no-load tap changers on the rectifier transformers, which gives no urgent need for condenser batteries (for the 480 V side where they had been installed, they are rather expensive). In general it was felt that it is simpler to cure the distorsion in the individual instrument instead of spending a considerable amount of money for dubious mains filtering.

The tap changer on the transformers (100, 85, 72 and 60°/o for the standard supplies) are apparently not so often adapted on the actual load voltage as it should be. Even if the magnet current is well known beforehand (approx. 1°/o) the user asks rather for a higher step to avoid saturation and if current change is required frequently he does'nt always ask for adaptation.(It costs time).

The high DC-currents to be handled lead often to water-cooled cables.

ANL-ZGS used ordinary cables with the inner conductors removed, the cables were protected with a PVC tube. SLAC used for truck chambers water-cooled cables for 15000 A for 200 m distance ($j \approx 4{,}5$ A/mm^2, losses $\approx$ 450 kW).

4.3. Remote control and interlocks

Supplies are remotely controlled in a straight forward way : direct multicore cable connection to the remote controlpanel which is normally equipped with volt- and ammeter, a kind of "Ready" indication and buttons for increase-decrease/coarse-vernier. In some cases indication for polarity, but no buttons for reversal. At LRL external potentiometers were also in use.

With the trend to "computerise" the beam transport D to A converters come in use. Fig. 11 shows the block diagram of the prototype seen at LRL, all resistors are metal film type, the FET switches use 2N4303 transistors (more details see sketch 7. n)). SLAC uses also stepping motor driven potentiometers with the possibility of position reading(shaft encoder), non linear potentiometer characteristic seemed to be part of the computer programme.

In general there is a trend towards DAC's equipped either with relays or FET switches. The latter seemed to have a 10^{-3} to 10^{-4} stability and reproducibility, but accuracy not better than 10^{-3}. (No precise figures could be obtained). The current was normally measured with shunts. Wherever groups of supplies were remotely controlled digital voltmeters were used. Manual remote control stations use the DVM's in connection with channel selectors computer controlled beams use DVM relay scanners. The BCD output (together with the scanner position) is fed back into the computer.

The interlock system is in all laboratories executed in a conventional manner (multicore cable directly from magnet to supply or supplies in case of LRL - see Fig. 10-)- Faults are indicated on the supply, no centralized indication. Interlock cable check (detects crossed cables); neither seen nor heard that it is planned.

The electronic chassis of the power supplies were either laboratory production (sometimes manufactured outside strictly according to prototype) or modified circuits if delivered originally by the industry. For the future people prefer to build the prototype and send out a hardware specification.

4.4. Computer controlled beam transport

One remark at the beginning : A small computer (which costs about $ 80.000) is in relation to other equipment fairly cheap. This fact might explain partly the advance of the U.S. laboratories in this field. About the usefulness of computers Dr. Green should be quoted : "The computer is an excellent device to do arithmetic rather than data logging". (BNL-AGS put a data logger in the warehouse after having recognized that nobody was interested in huge amount of paper produced).

Two typical applications should be discussed briefly. The closed loop LRL injection system and the SLAC "A" beam control.

The LRL Bevatron injection system (operating with 3 magnets and 2 lenses) is equipped with position electrodes (Fig. 12) connected to amplifiers with non-linear feedback elements to obtain a linear relationship between beam position and steering magnet current. These amplifiers are followed by sample and hold amplifiers,each correcting the corresponding upstream element.

For external proton beams the number of beam transport elements involved is much higher and the principle is very similar in all laboratories : magnets and lenses having a well defined relationship in respect of the beam which can easily be translated into a programme are grouped together. Several groups are then operated from the same computer.

The SLAC switchyard beam control is a typical example. Fig. 13 explains the basic idea, the following will give some details about the adjustment procedure. The programme is written in such a way that a certain percentage current increase (or decrease) for one or more magnets can be performed. In case the beam gets lost all influenced magnets can be put back to initial conditions by a simple instruction. For setting of a specific current no high accuracy and linearity for the DAC is required. After first step the difference between DVM reading and setting will be calculated and corresponding correction given to DAC (2nd step) and so on. Facilities are given to perform a check every 10 sec. (print out) or only if a certain supply is out of a certain tolerance.

It was not my task to study the methods of computer controlled beams rather than gather some information valuable for the future construction of power supplies.

There is for instance a clear trend towards digitalized reference sources (DAC's) equipped with FET-switches, for pulsed supplies a necessity, but brings the earthing problem up - reference and digital input common are identical - . For higher precision (10^{-4}), relay DAC's seem to be still in favour (also in respect of potential separation). The fidelity between setting current and DVM read out (offset, linearity) does not seem very important (even the DVM indication need not be absolute), only a good long term stability (about 10^{-4}) is required. Theoretical linearity, offset, etc. need not be better than 1°/o, if current variations of percent order should be predictable within 10^{-4}. The "initial settings" for a given energy is always found empirically. The settings for the desired energy range will be obtained from specially written interpolation programme.

D. Evans (LRL) emphasised that the success of a computer controlled beam transport depends mainly on an excellent programmer with a good knowledge in beam handling and who should also be experienced in data transmission (including construction of not commercially available interface equipment). Physicists seem to be happy to get a stable beam instead of losing their time in fiddling with complicated beam lines.

Some remarks about low level signal handling and transmission : up to 52 twisted pairs in one cable are available in the U.S. and tried out with success in combination with IC line drivers and receivers. Most of troubles came from closed earth loops. Higher threshold level IC logics would be an advantage, circuits designed with TTL-IC's have to be often modified (filtering, potential separation, "supporting" condensers, etc.).

Normally the computer is installed very near to power supplies in small control centres so that special transmission techniques (multi-or carry-plex, pulse-code modulation, etc.) have not to be used,

The SLAC SDC 9300 (a $ 250.000 machine with 32 K memory) is the only case of a computer working in time sharing : power supply control and spectiometer experiments. It is planned to separate the two functions (use of smaller computers).

In general people are so open minded about computers that a 3 months running in time will normally be granted and later "imperfections" to certain extent tolerated.

5. GATE CONTROL SYSTEMS

5.1. Circuits for main magnet supplies

Grid (or gate) control sets in this category have to fulfill at least two conditions : a) very low tolerances between consecutive pulses over the whole control range are permitted 1/10 to 3/10 of a degree to keep the subharmonic level low and b) easy and precise setting of firing angles to establish a good reproducible magnet cycle.

BNL-AGS intends (F.G. Cottingham) to build the grid control set for the converted AGS partly themselves.

Of particular interest is the proposed circuit to compensate subharmonics individually (Fig. 14).

To reduce i.e. the 60 cps component all phases will obtain a signal which obeys the law $1/\sin\Theta$ and $1/\cos\Theta$. By proper dimensioning of the resistor network according to $\sin\Theta$ and $\cos\Theta$ (the reciprocal value will be obtained by making $R >> r$). By this method only one subharmonic will be influenced but for all phases at the same time. The amplitude of the other subharmonics will not be changed. The minimum will be indicated by the meters (tuned to the subharmonic in conjunction with sample and hold circuits).

5.2. Circuits for beam transport supplies

The situation is different from 5.1 gate control sets used in current regulation loops will have a considerable hum level of at least a few percent at the input which determines the precision of consecutive pulses. The precision required with smoothed dc at the input need not be better than about one degree. The ramp trigger should be insensitive to sine wave distortions, so that the older industrial gate control sets having a sine wave comparison (self compensating against mains variations but also misfiring due to commutation notches of other rectifiers) have to be replaced by the ramp type or filtered sine wave input (losing at the same time the compensating feature). Thyristor supplies are mainly equipped with the ramp type (double ramp per cycle for the 180° shifted phase). Digital gate control sets (i.e. on the base of a voltage to frequency converter with frequency dividers for each phase and fixed adjusted coincidences) are not in use but there is a great interest.

At NAL (R.Cassel) are some ideas in this direction but nothing concrete yet.

6. MISCELLANEOUS

It is believed (BNL-AGS) possible to get Integrated circuitry more reliable by the use of Large Scale Integration (Fairchild), but they are not yet cheap enough for smaller quantities. There is some chance probably later, if one could make profit of circuits developped for other customers. A complete circuit composed of about 100 logic elements may cost ~ $ 50.

In general model shops and electronic laboratories are remarkably well equipped with modern tools and measurement equipment.

The highest degree of uniformity in panel and chassis design was found in SLAC control rooms. There must be a certain standardisation of lamps, push buttons numerical displays, etc. Remarkable was the high amount of 19 inch chassis compared with plug-in units (these are more frequent in the nuclear electronics field). The chassis, more or less densely packed seem to be mainly function oriented. In the control rooms more than 80°/o of the installed chassis are not commercial instruments.

Seen at NAL Oakbrook : Microfilm display of hardware catalogues combined with xerox machine.

7. REPORTS AND NOTES OBTAINED

a) BNL Passive filters for the converted
AGS Flat top — J.G. Cottingham
AGSCD-5
Nov. 10, 1965

b)	BNL	The use of passive filters and rectifier commutation timing to accomodate injection of low $\dot{B}$. AGSCD-44 Apr. 13, 1966	J.G. Cottingham
c)	BNL	Total filtering system for converted AGS flat top. AGSCD-88 Jan. 9, 1968	J.G. Cottingham
d)	BNL	Feedback systems to reduce subharmonic ripple in a multiphase rectifier. AGSCD-30 Feb. 14, 1968	J.G. Cottingham
e)	BNL	List of AGS Experimental magnets.	
f)	BNL	Specification for AGS Experimental magnet DC power supplies - Silicon controlled rectifier type (21 pages, 4 drawings). Spec. AGS-362 Dec. 7, 1966	
g)	ANL	Calculation of MVA, MVAR and MW requirements of accelerators operating directly off the utility with particular emphasis on ZGS standby operation. Apr. 11, 1968	A. Rohrmayer
h)	ANL	ZGS standby operation directly off the utility. Engineering notes Apr. 29, 1968	A. Rohrmayer

i) ANL Schematic diagrams for the different alternatives to g) and h).
15 sketches — A. Rohrmayer

j) NAL Power connections of main ring power supply with shift transformers.
(2 drawings) — R. Cassel

k) NAL Motor flywheel stored energy system and voltage, current and power waveforms.
(4 drawings) — R. Cassel

l) LRL High-stability wide-band low noise transducto circuit suitable for high precision magnet current regulators — W.L. Gagnon, B.H. Smith
UCRL-16789
June 22, 1966

m) LRL Digital to analog converter.
Engineering sketch

n) LRL Transistor heat sink (water-cooled). — W. Flood
(4 drawings)

p) SLAC The SLAC beam switchboard control computer — S.K. Howry, R. Scholl, E.F. Seppi

IEEE Transactions on Nuclear science. — M. Hu
June 1967 — D. Neet

q) SLAC Data assembly building.
(power supply arrangement for A, B and C-beam)
(11 layout and arrangement drawings)
6 power supply distribution lists

<u>Distribution</u> (open)
MD/4 and SI/1 lists

PS/RM/fm/6608

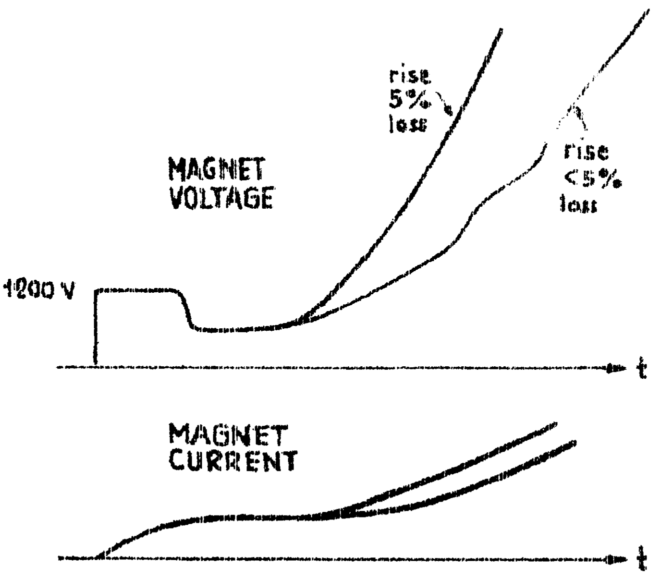

Fig. 1 BNL-AGS Frontporch with 50 MeV injection

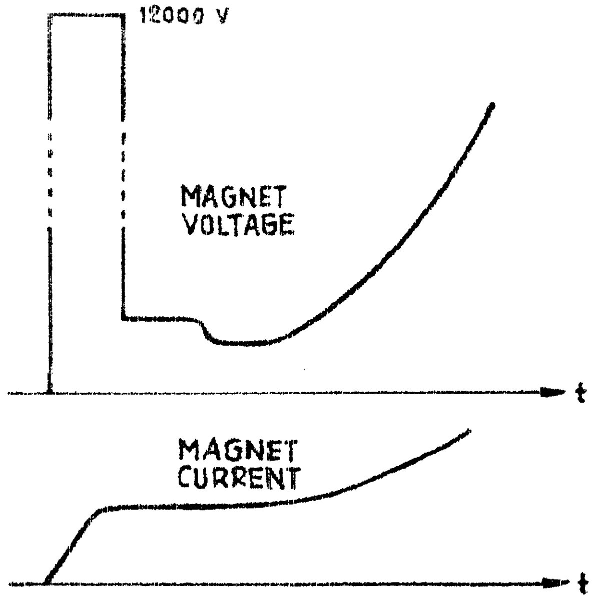

Fig. 2 BNL-AGS Frontporch with 200 MeV injection

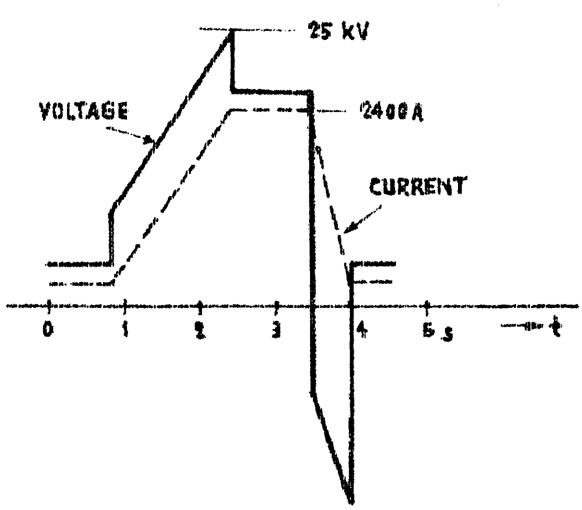

Fig. 3 NAL Magnet Cycle

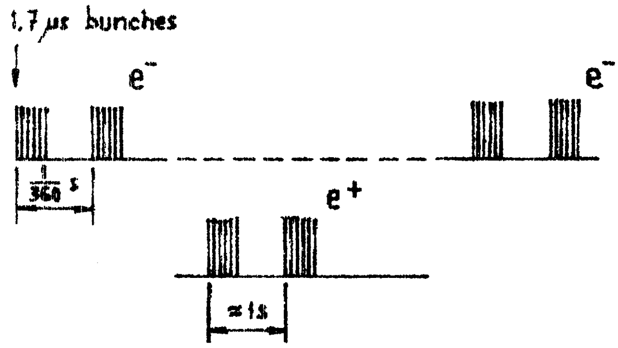

Fig. 4 SLAC "Cycle"

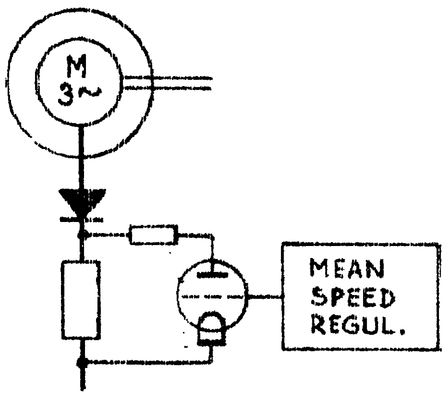

Fig. 5 Rotor Circuit of the driving motor

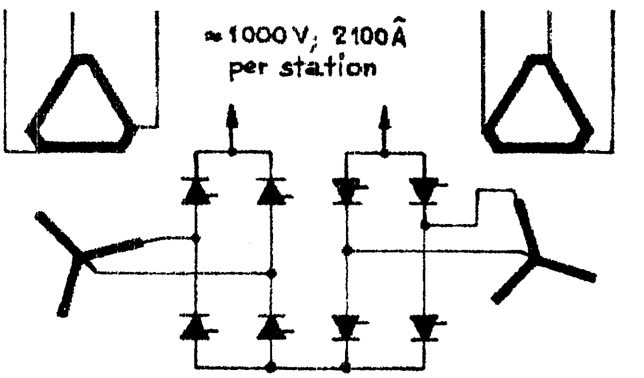

Fig. 6 NAL Rectifier Circuit (±15° phase shifted 3-phase bridges with freewheeling thyristors)

15. 6. 68.

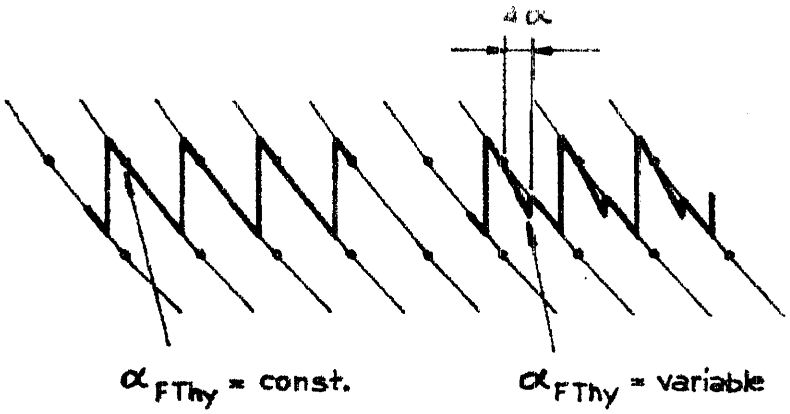

Fig. 7 CERN-Booster (left) and NAL (right) Freewheeling Thyristor control

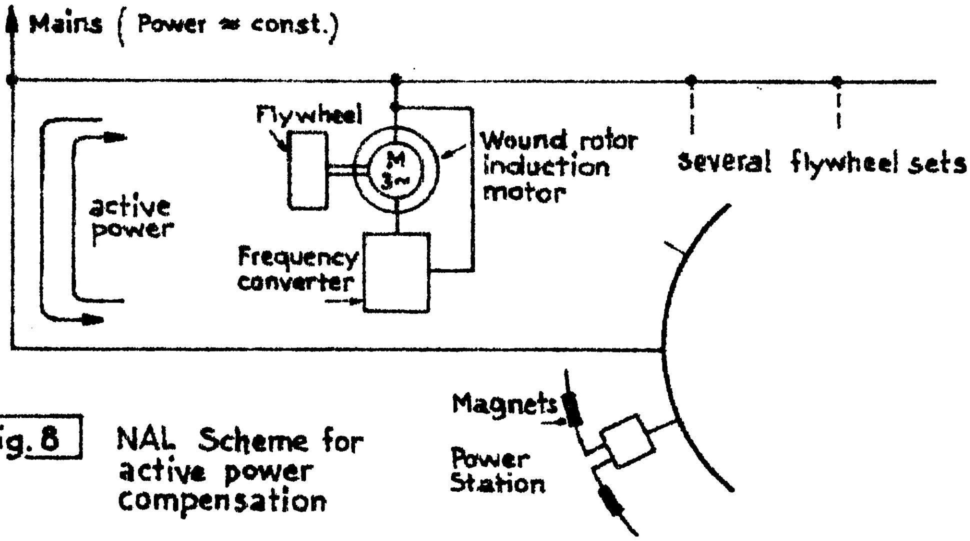

Fig. 8 NAL Scheme for active power compensation

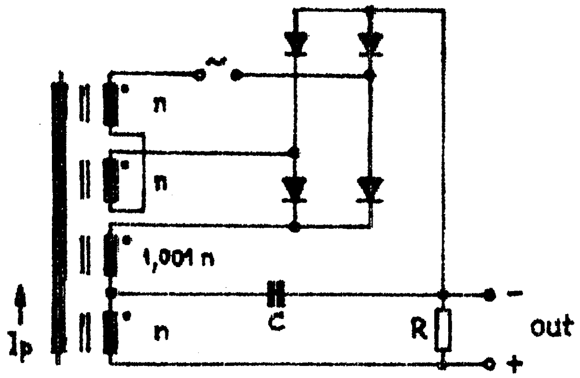

Fig. 9 4-core transductor

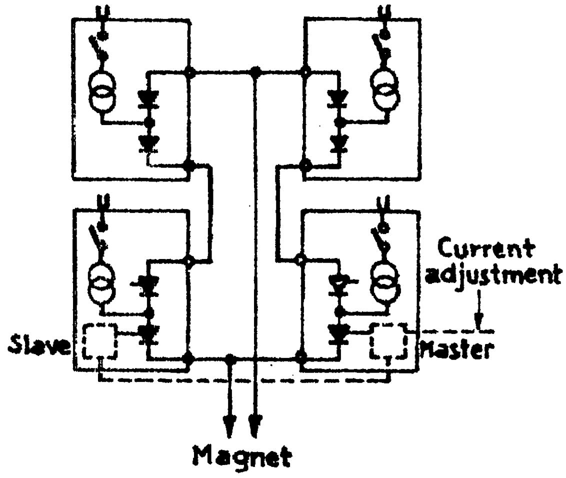

Fig. 10 LRL Series-parallel connection of diode- and thyristor supplies

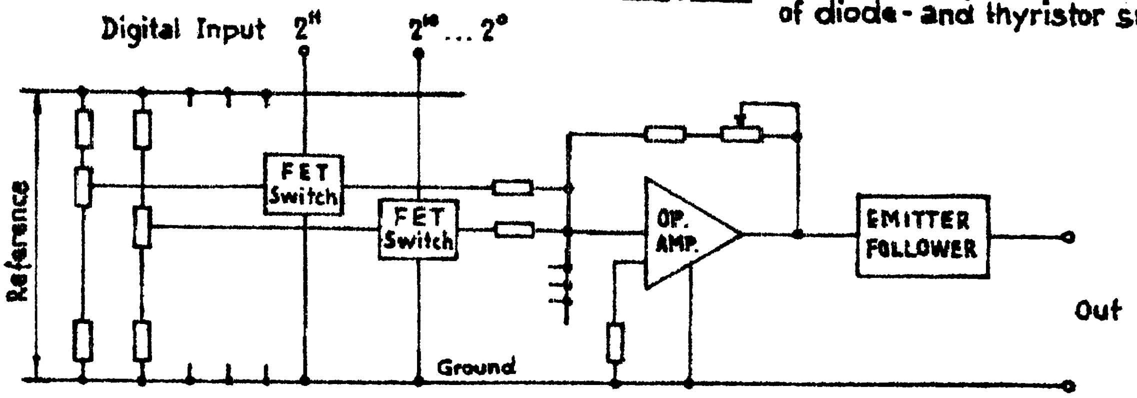

Fig. 11 Simplified Block diagram D/A converter LRL

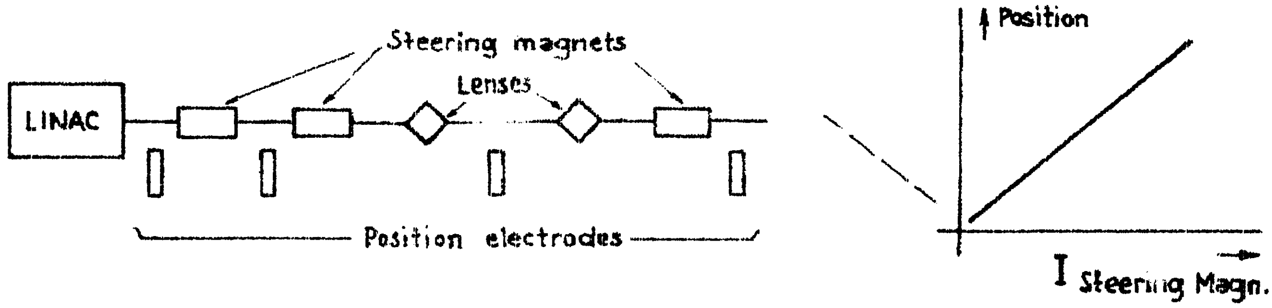

Fig. 12 LRL closed loop injection control

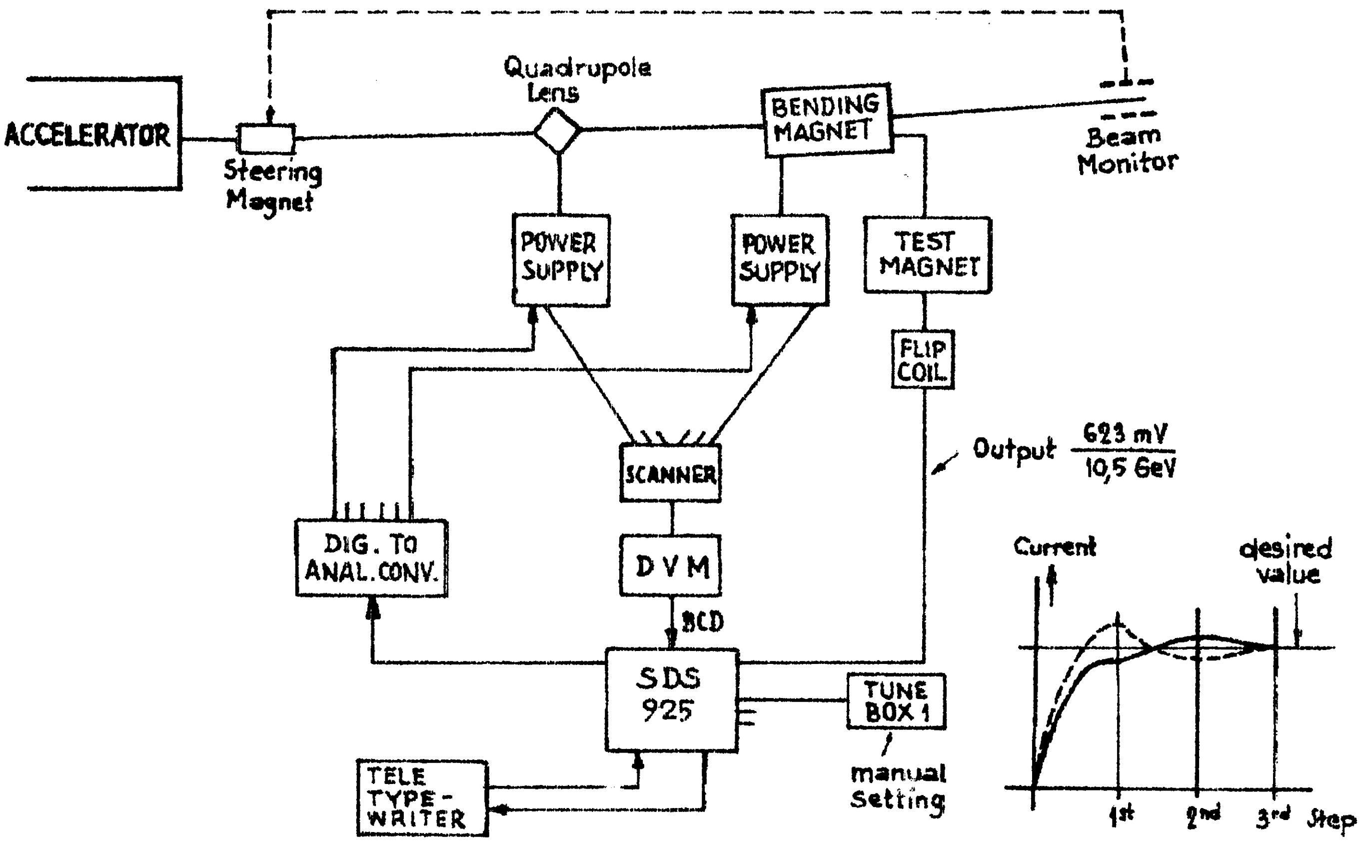

Fig. 13 SLAC Switchyard beam control

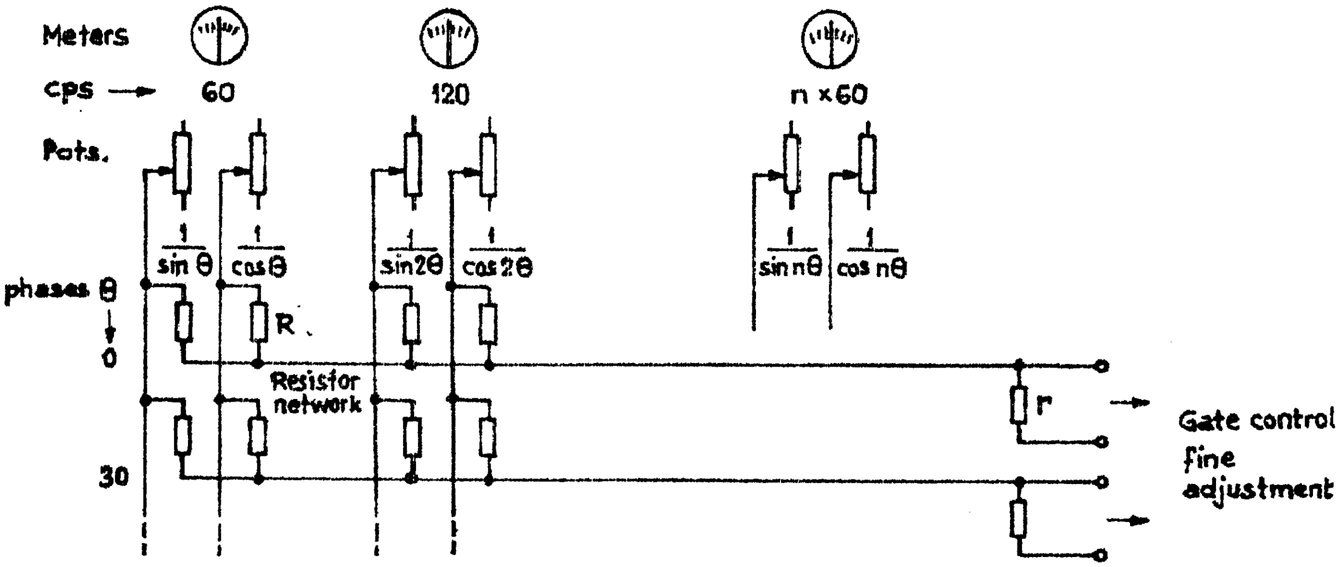

Fig. 14 BNL - AGS Individual subharmonic compensation circuit

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