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Notes on the RHIC Injection Kicker

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Brookhaven National Laboratory

U.S. Department of Energy

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AD/RHIC/RD-85

RHIC PROJECT

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Introduction

The basic design of the RHIC injection kicker has been completed. However a good deal more must be done before the system is operational in RHIC. The purpose of this note is to discuss the outstanding issues and offer guidance on solutions.

Charging

The prototype uses a Maxwell switching power supply which provides an essentially constant current. The charging time is 3.3 ms to full rated voltage (70 kV). This value seems a good compromise between peak charging power and the necessity of minimizing the time the kicker spends fully charged. The repeatability is 0.1%. The nominal strength of the kick is 0.186 Tm but a somewhat lower force may be needed for polarized proton injection. Thus the charging level must be adjustable, depending on the species injected. Recent concern over the cost of the charging supply has prompted a look at resonant charging, using a step-up transformer from a large, low voltage, capacitor bank. Evaluation is still in progress.

Although there is a case for four separate power supplies similar to the present prototype, the simplest, most reliable system, would be a common supply providing about four times the current of the present prototype. A new specification will have to be written for this supply - see also the comments under "60 Hz Supply" concerning the power source for charging supply. Each pulser would be charged through an isolating resistor of about 1000 ohms. It appears the best place to locate the charging resistor is in the end-box housing the thyratron. Between the charging supply and the pulsers it will be necessary to install a cabinet containing a HV safety relay and four removable links, so that any single, selected, pulser can be energized or isolated for trouble-shooting purposes, see Fig. 1.

60 Hz Power

The analysis of the grounding system* indicates that ground transient voltage should be isolated from the 60 Hz feeders. The best way to achieve this is to provide a 60 Hz isolating transformer which provides all electrical power to the four pulsers. The primary and secondary winding can be insulated for the 10 kV withstand level suggested in note AD/RHIC/RD-84. The primary should be shielded. In a memo to T. C. Nehring dated 6/11/93 it is suggested that five 208 V breakers be provided in the 5 o'clock house. The memo is attached as Appendix 1. This should be modified as shown in Fig. 2. In this scheme an isolating transformer of approximately 50 kVA rating provides power for all four pulsers. Most services, such as filament and reservoir supplies, the control system, trigger generators, etc., can be supplied from 115 v, single phase. The charging supply can be supplied with the 3 phase voltage best suited for the design of switching system, the secondary voltage can then be the designer's choice.

Control and Instrumentation

The basic controls are planned to be PLC based and will follow the RHIC protocols. Local control will be provided at the 5 o'clock house, presumably outside the cage. All controls should be designed with the possibility of ground transients in mind, i.e., no

* Notes on the RHIC Injector Magnet Ground System, E. B. Forsyth, AD/RHIC/RD-84, January, 1995.

conductor connections to the rest of the RHIC control system. Optical isolators should be used. Each pulser will be equipped with a current transformer monitoring load current. This waveform will be essential in order to adjust timing synchronization of the kicker pulse with the incoming bunch. This waveform should be digitized and transmitted to the control room with very stable time delays. The prototype pulser has a current transformer in the thyratron cathode circuit, this will not be necessary in the operational units.

It is suggested that the following circuit operating characteristics be monitored automatically. Many, if not all, of these measurements should be available for inspection at the local control point and some in MCR. Operation outside the threshold limits may operate the interlock or be displayed as an aid in trouble-shooting.

1) Thyratron filament current
2) Thyratron reservoir current
3) Grid bias voltage
4) Prime waveform
5) Trigger waveform
6) Load waveform
7) Integrated load waveform (average of four pulsers)
8) Charging voltage level - interlock on high side
9) Time at voltage too long - suggest about 1 ms for this window - interlock
10) Time delay from trigger to start of flat-top of the load waveform
11) Jitter of above delay time
12) Synchronization of the four load waveforms (equal time delays)

13) Line voltage

14) Oil level in storage line, thyratron box and terminating resistor - interlock

15) Oil pressure in storage line, thyratron box and terminating resistor

The control functions presently provided for the G-10 AGS fast kickers are shown in Appendix II. Much of this design can be used directly with the RHIC injection kickers. Minor differences which must be resolved are:

1) Four high voltage shorting relays are used in the AGS, the scheme shown in Fig. 1 only requires one relay plus manually operated links. If necessary the links could engage interlock switches when properly in position.

2) Total delay of each pulser should be monitored.

3) Time at voltage should be monitored - this will avoid the pulser staying at voltage if the trigger is late or missing.

Timing

The trigger will be generated by the low level RF systems of both the AGS and RHIC. The beam in the AGS must satisfy constraints on the energy and synchronization with the receiving bucket in RHIC. The total kicker delay time, including cable delays and anode delay is an important component of synchronization. Before the RHIC filling cycle begins it is recommended that the kicker be operated for a minute or so to establish the anode delay time as in 10) above. The latest measured value can then be used to generate the anticipation delay so that the receiving bucket is located at the kicker when flat-top of the deflecting waveform occurs. It is possible that the delay time will not be the same for each pulser, in this case the trigger time will be determined for each pulser. Some experimentation to clarify this situation will be needed once four pulsers are installed and operating. The final version of the trigger generator for the thyratrons has to be built nd tested.

Pulser

So far two thyratrons have been tested in the prototype: C X 1168A and C X 1168C. The "C" model is designed for fast rise-time and high di/dt, but requires more power for the filament and reservoir, and it costs more. It is recommended we stick with the C X 1168C until the performance of the kicker in the sextant test has been determined. If there is some margin the rise-time may be sacrificed to lower the cost of the next kicker system. The filament and reservoir supplies should consist of regulated dc supplies locally adjustable over a useful range. Say ± 10% of nominal for the filament supply and ± 20% of nominal for the reservoir supply Regulation should be 1 to 2% over a ± 15% line voltage variation. The bias supply and trigger generators should be energized from regulated ac sources.

High reliability is essential. One option under discussion is to build a spare pulser so it can be quickly brought on line if a pulser fails. However this will require duplicate hard-wired, filament, reservoir, bias and instrumentation. Only the coax cables to the magnet, the charging connection and the trigger will be relatively easy to move from a defective pulser to the spare. The high voltage components may require "seasoning" after standing idle for a long period, hence the spare may not be too useful anyway. Thus it is suggested that room be left in the cage for a spare but only four pulsers be built for the sextant test. If this test reveals the reliability of the complete system would be enhanced by an "on-line" spare then the systems for both the blue and yellow rings can include them by the time RHIC is operational.

The rise-time has been improved by means of an R-C network in parallel with the thyratron. Due to system non-linearities the correct value can only be chosen at the operating voltage. Also the magnet response depends on the length, hence final values must be determined when a full-length, high-voltage version of the magnet is available. A parts list is needed of all the components comprising the pulser unit. The recommended oil is Calumet Caltran 60-15.

Magnet

The endurance of a full-length magnet at operating voltage plus 20% (~ 60 kV) has to be demonstrated. Integral field measurements on a full-length magnet are still needed to determine the exact charging voltage corresponding to the nominal deflecting force of 0.186 Tm. Minor design changes are still possible, for example improved rise-time or lower reflections may result from switching dielectric for ferrite sections at the input and output ends of the magnet. Some improvement is needed in the sealing of the oil chamber containing the terminating resistor. Experience at SLAC indicates it is essential to closely match the propagation times of the two paralleled cables connecting the pulser to a magnet. In addition the propagation time of the four pairs must be matched. These tolerances have not been determined.

A grounded outer conductor removes the possibility of flux linking the machine vacuum chamber. This means the original design can be adopted which utilized the electric field as well as the magnetic field to deflect the beam. In this case all magnets would be mounted the same way with the wave propagating in the opposite direction to the beam.

It is estimated the electric field would provide ≈ 7% of the kicker, thus permitting the charging voltage to be reduced by the same percentage.

Beam Tube

The problem of dealing with microwave resonances in the kicker magnet structure has not been resolved. Low frequency resonances appear to be greatly reduced by ensuring the image currents in the beam pipe can flow in the outer conductor of the magnet. This condition requires the magnets to be grounded in the ring, see note AD/RHIC/RD-84. High frequency resonances occur at about 1.0, 1.72 and 2.7 GHz. Although these resonance can be removed by coating the inside of the ceramic tube by a high conductivity layer (typically 1 to 10 Ω/□) this layer can adversely affect the magnetic and electric fields of the kicker itself. Too low a resistance will increase the rise-time of the current waveform and cause the central field to decrease. In addition the grounded layer forms a boundary for the electric field which greatly increases the electric field stress in the wall of the ceramic tube and the gap between the tube and the magnet structure. Breakdown in the first coated beam tube occurred in the region between the tube and the magnet at less than 15 kV. A more elegant solution is to place microwave absorbent ferrite or dielectric* on the inside or outside of the tube, or in the spaces at the ends of the magnets. If properly chosen such an absorber will have little effect on the performance of the kicker but will reduce the observed microwave resonances. A high resistivity coating will be required to conduct accumulated charge from the wall to ground. A surface resistivity of ~ 20 k Ω/□ has yet

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*I. E. Campisi, "The Workshop on Microwave-Absorbing Materials for Accelerators, IEEE Trans of 1993 Particle Conf, p. 1115.

to be developed and tested. All the coatings on the inside of the beam tube should have a very low outgassing rate consistent with the UHV requirements. All coatings (inside or outside) should be capable of 200°C bake-out. R&D on the beam tube design should continue, a plain ceramic tube will be suitable for the sextant test, the final beam tube design will not be needed until RHIC is operational.

Safety

Three issues are:

1) Grounding
2) High Voltage
3) Oil

1) Grounding

The options have been discussed at length in Note AD/RHIC/RD-84. Basically three grounds are needed:

1) The magnet ground in the ring
2) The pulser equipment ground in the 5 o'clock house (the pulser itself is NOT grounded in the house)
3) Building ground at the 5 o'clock house

The use of a dedicated ac feeder transformer, described above, will minimize the coupling of ground transients into the line. It will be important to ensure circuits referenced to one ground are not in advertently connected to another ground. For example, instrumentation at the magnets, such as oil pressure in the terminating resistor, can be referenced in two ways:

1) Referenced to ring ground, in this case the signal must be suitably isolated from the control system.

2) Referenced to pulser equipment ground, in this case the transducer must be isolated from the magnet ground.

2) High Voltage

All high voltage components are enclosed. An interlock system must be designed for panels which must be removed for servicing, for example the cabinet containing the "links" to isolate each pulser from the charging supply must be suitably interlocked. Ground sticks must be provided at locations which can be accessed for servicing - it is recommended a low ohmic value, high voltage resistor such as a "globar" be placed in series with each grounding lead to minimize peak current. A key system to "enable" the H.V. "on" circuit must be designed.

3) Oil

Suitable catchments should be designed for the oil in the Blumlein, the thyratron box and the magnet terminating resistor. The oil-filled spaces should also be monitored for oil level and oil pressure, as mentioned above. Oil filling and draining procedures must be documented and appropriate equipment provided in the 5 o'clock house.

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BY EBE DATE 1/20/95 SUBJECT RHIC INJECTOR KICKER SHEET No. ____ OF ____

CHKD. BY ______ DATE ______ JOB No. ______

DEPT. OR PROJECT AGS

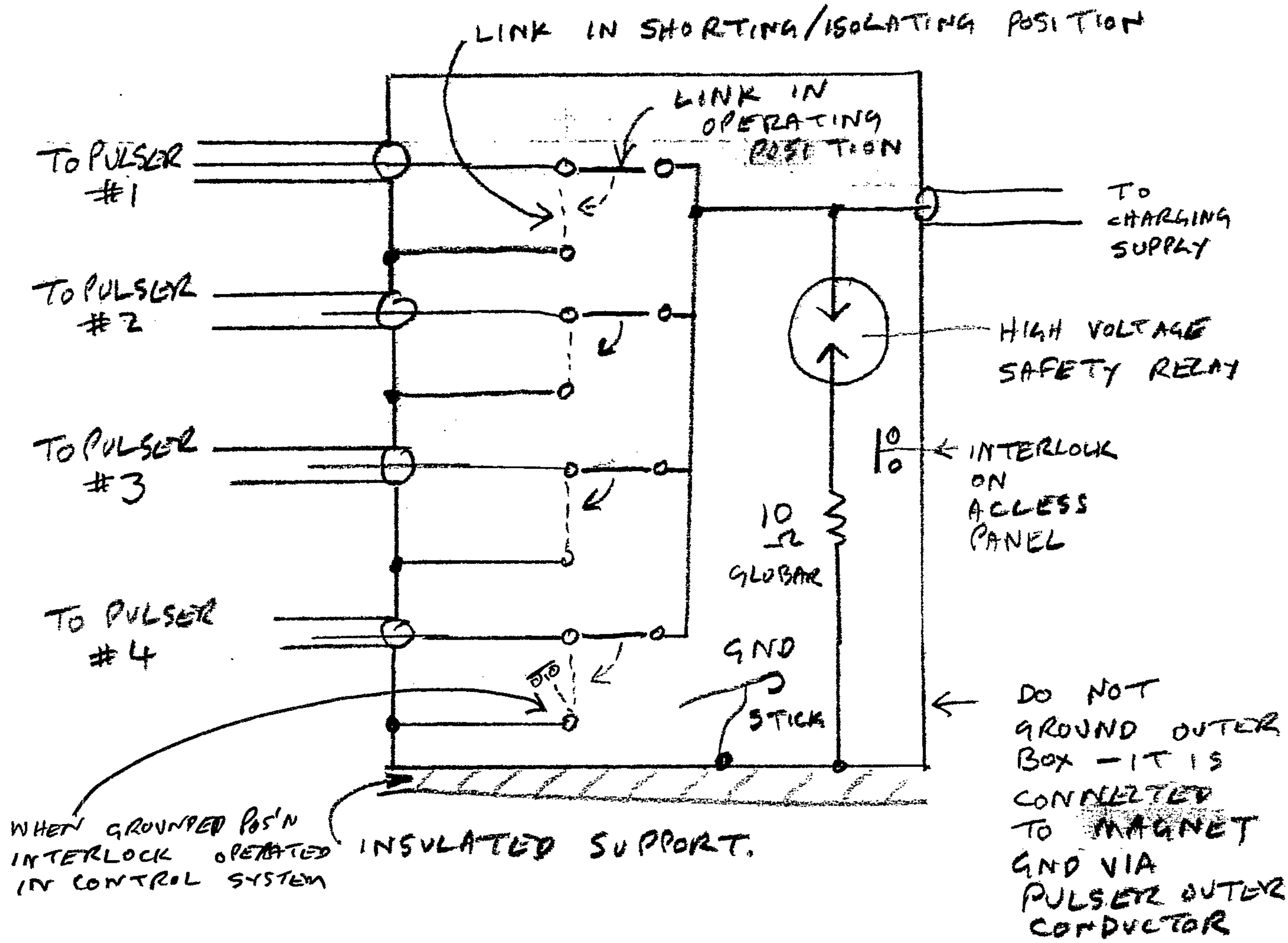

FIG 1. OPERATE/ISOLATE SELECTOR BOX

SP 11037A

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BY EBF DATE 1/20/95 SUBJECT RHIC INJECTOR KICKER SHEET No. ___ OF ___

CHKD. BY ___ DATE ___ JOB No. ___

DEPT. OR PROJECT AGS

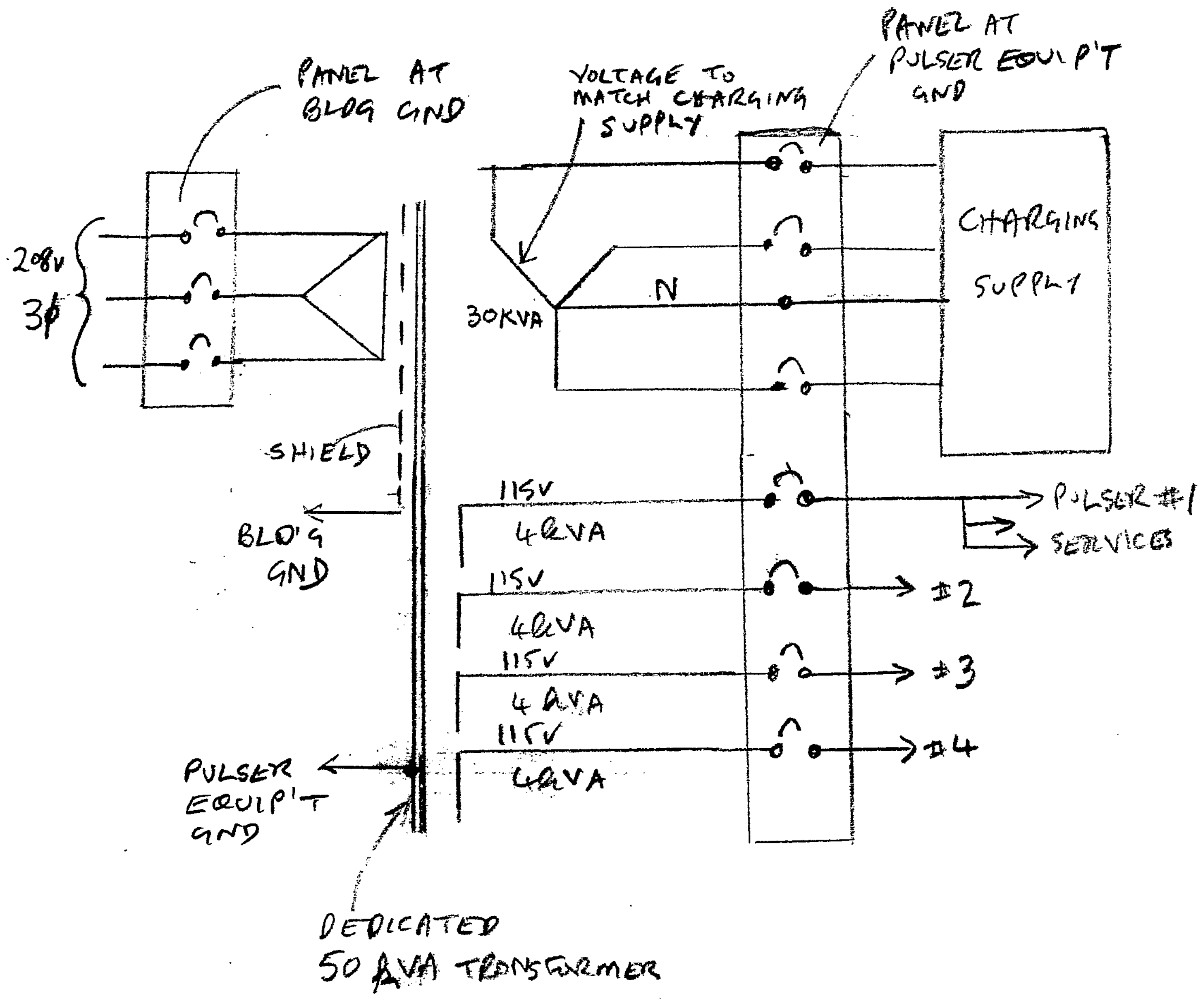

FIG 2. 60HZ FEEDER SYSTEM FOR 4 PULSERS

SP 11037A

APPENDIX I

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: Friday, June 11, 1993

TO: T.C. Nehring

FROM: E.B. Forsyth

SUBJECT: **60 Hz POWER FOR RHIC INJECTION KICKER**

At the moment, there is some experimental work needed before the design of the injection kicker is finalized. In the worst case, each ring will require one charging supply and four pulser units. All these units are designed for 208 V, 3 phase, 5-wire feed. A conservative rating for each breaker would be 60 A phase current, thus each house requires five each isolation breakers rated for 22 kVA.

We hope to supply the kicker magnets using only two pulsers, in this case each pulser would require a 90 A phase current but the charging supply remains the same. For this option each house would require two isolation breakers supplying 33 kVA and one supplying 22 kVA, all at 208 V, 3 phase, 5 wire.

mvh
Copy to:
H.W. Foelsche
A.J. McNerney
S. Soukas
A. Zhang

MONITOR.XLS

RHIC INJECTION FAST KICKER PROJECT	**2/10/95**
ANALOG METER:	
Thyratron Reservoir Voltage	A, B, C, D
Thyratron Reservoir Current	A, B, C, D
Thyratron Filament Voltage	A, B, C, D
Thyratron Filament Current	A, B, C, D
Thyratron Prime Grid Voltage	A, B, C, D
Thyratron Bias Grid Voltage	A, B, C, D
High Voltage Power Supply Charging Voltage	
High Voltage Trigger Power Supply Charging Voltage	
Load Resistor Current Waveform	
Fiber Optic Isolated Analog Signal (individual or summation)	
Charging Power Supply Output Voltage Waveform	
Monitoring Point of Trigger Waveform	

Due to recent design change of 10kV floating deck requirement, the charging power supply interface unit will have to be redesigned to cope with the high voltage isolation level. Or, the power supply vendor will have to change the control interface of the power supply with stand of 10kV pulse and DC voltage.

SYSTEM STATUS	
1=Remote, 0=Local	O:030/00
1=Off	O:030/01
1=Stand By	O:030/02
1=Reset	O:030/03
1=Ready	O:030/04
1=In Process	O:030/05
Spare	O:030/06
1=Control Power On	O:030/07
Trigger Power Supply 1= HV On	O:030/10
Charging Power Supply 1 = HV On	O:030/11
Pulser On 1=Normal	O:030/12
System 1=Fault	O:030/13
1=Normal A	O:030/14
1=Normal B	O:030/15
1=Normal C	O:030/16
1=Normal D	O:030/17
1=Beam Dump Fault	O:031/00
1=Vacuum Fault	O:031/01
1=Rack A Open	O:031/02
1=Rack B Open	O:031/03
1=Local Fence Open	O:031/04
1=Ring Fence Open	O:031/05
1=Trigger PS Fault	O:031/06
1=Charging PS Fault	O:031/07
Reserved for Charging Power Supply Status	O:031/10
Reserved for Charging Power Supply Status	O:031/11
Reserved for Charging Power Supply Status	O:031/12

Reserved for Charging Power Supply Status	O:031/13
Reserved for Charging Power Supply Status	O:031/14
Reserved for Charging Power Supply Status	O:031/15
Reserved for Charging Power Supply Status	O:031/16
Reserved for Charging Power Supply Status	O:031/17
1=Grounding Relay A Open	O:032/00
1=Pulser A Fault	O:032/01
1=Grounding Relay A Fault	O:032/02
1=Prime A Fault	O:032/03
1=Bias A Fault	O:032/04
1=Reservior/Filament A Fault	O:032/05
1=Pressure A Low	O:032/06
1=Oil Level A Low	O:032/07
1=Grounding Relay B Open	O:032/10
1=Pulser B Fault	O:032/11
1=Grounding Relay B Fault	O:032/12
1=Prime B Fault	O:032/13
1=Bias B Fault	O:032/14
1=Reservior/Filament B Fault	O:032/15
1=Pressure B Low	O:032/16
1=Oil Level B Low	O:032/17

1=Grounding Relay C Open	O:033/00
1=Pulser C Fault	O:033/01
1=Grounding Relay C Fault	O:033/02
1=Prime C Fault	O:033/03
1=Bias C Fault	O:033/04
1=Reservior/Filament C Fault	O:033/05
1=Pressure C Low	O:033/06
1=Oil Level C Low	O:033/07
1=Grounding Relay D Open	O:033/10
1=Pulser D Fault	O:033/11
1=Grounding Relay D Fault	O:033/12
1=Prime D Fault	O:033/13
1=Bias D Fault	O:033/14
1=Reservior/Filament D Fault	O:033/15
1=Pressure D Low	O:033/16
1=Oil Level D Low	O:033/17