Technical Systems Configurations - Electrical

Subsystem: Vacuum Electronics
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1. Requirements:

Vacuum Electronics provides ion pump power, control and monitoring to all vacuum structures in all accelerators and Power RF systems. Ion pumps service beam pipes, accelerating structures, power delivery systems, power sources, cavities and injection/extraction beamlines. Pumps range in size from very small (25 liters/sec.) to very large (1500 liters/sec.) depending on machine application. Very small pumps are found throughout the main linacs; slightly larger units serve the RF delivery systems, and the largest units are found in the large cross-section vacuum structures in high radiation areas of the damping rings. Titanium sublimation pumps (TSPs) are found in the rings and Turbo roughing pumps in each sector alcove where the RF power systems are located. Current and voltage readout of each ion pump are normally required in order to monitor proper operation. The pump current gives a useful measure of vacuum. More precise measurement requires gauges, which are located in strategic locations near valves to serve as a redundant part of vacuum protection. Finally, valves are used to isolate parts of a vacuum system that require maintenance to minimize impact of leaks or maintenance work on the total vacuum system.

Vacuum electronics plays an integral role in machine operation and protection. When vacuum degrades for any reason in a part of the machine, action must be taken instantly to avoid damage from the beam. The sensors used are the individual pump currents, read out by the control system, and independent gauges that can trip nearby valves without depending on the control system. Temperature monitoring of the vacuum system (See EConfig-Temp 032101) provides another layer of protection.

The Vacuum Electronics must be both robust and low cost per unit because of the very large number of pumps (~14,000) in the accelerator. Numbers and types of pumps, gauges and valves in the various machine areas are shown in Tables 1.1 - 1.3.

	Kly Alcove/ Long Sec		Tunnel/ Long Sec		Drift/ Long	Tot RF	Tot Drft
Pumps	Klystrons	Manifold	DLDS	Beamline			
25 l/s	216			216		4752	
75 l/s		18	288			6732	
300 l/s					12		264
Totals	216	18	288	216	12	11484	264
					Grand Total		**11748**

Table 1.1: Ion Pump Quantities & Types for Both Main Linacs
(22 RF & 22 Drift Long Sectors)

	INJECTION AREAS	DAMPING RINGS		
Pump L/s	Qty	Qty	Subtotals	**Totals**
Ion Pumps				
25		411	411	
30	75		75	
75		106	106	
200		108	108	
300		78	78	
400		94	94	
500	500		500	
				1372
Titanium				
600		116	116	
1200		84	84	
1500		116	116	
				316
Turbo				
V300SF		11	11	**11**

BEAM DELIVERY	Pumps l/s	Total
	30	618
	Total	**618**

Table 1.2: Pump Quantities & Types for Injection, Damping Rings & Beam Delivery

ITEM	MAIN LINACS	INJECTION & DAMP. RNGS	BEAM DEL'Y	TOTALS
Gauges				
Valves				

Table 1.3: Gauges & Valves Summary

2. Technical Description

2.1 Architecture: The design concept used for cost modeling for the ion pumps is based on the model shown in Fig. 2.1. Each sector of the main linacs is supported by a pump power supply that produces 5000VDC at ~1mA, 5W maximum for a 25 l/s pump. Redundant bulk power supplies at 48 V, situated in protected areas, drive a redundant power rail that supports only the vacuum system (not the TEEs). Power is switched to low voltage AC in the tunnel near the pump and transmitted by an individual jumper cable to a step-up transformer, radiation-hard HV diode and filter capacitor situated on the pump connector, to rectify the power to DC. Ideally the transformer would have a sagging I/V characteristic so more current could be drawn at lower voltage (Eg. 10 mA at 500 V, 1 mA at 5 kV, maintaining 5 W maximum power dissipation for a 25 l/s pump), to provide more efficient pumping during the initial pump-down. Figures 2.2 and 2.3 show the concept (M. Browne). Once pump-down achieves low pressures, a 25 l/s ion pump standing current reduces to nanoamperes and power dissipation to less than a watt. Fig. 2.4 shows clustering of 75 l/s pumps in the main linac DLDS system for a typical distribution line (M. Neubauer). The uneven distribution emphasizes the need for flexibility in the readout architecture along the machine.

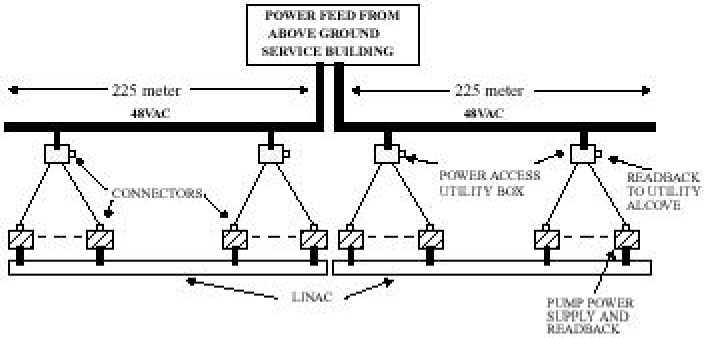

Fig. 2.1: Vacuum Ion Pump Tunnel System Concept (D. Nelson)

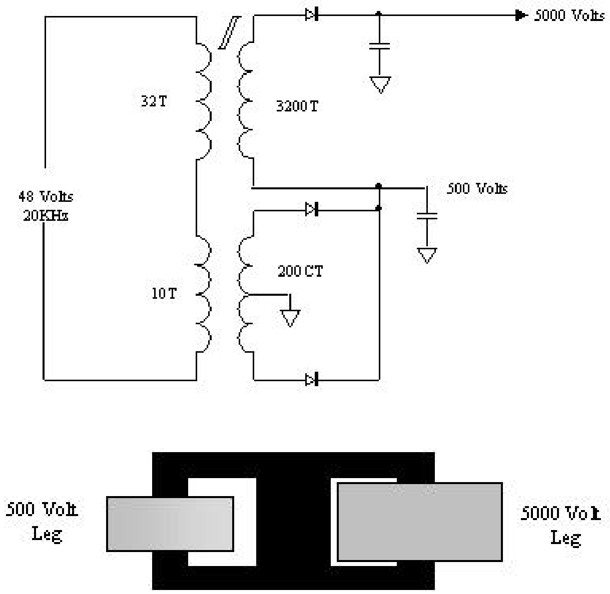

Fig. 2.2: Saggy Transformer & Rectifier Concept (M.Browne)

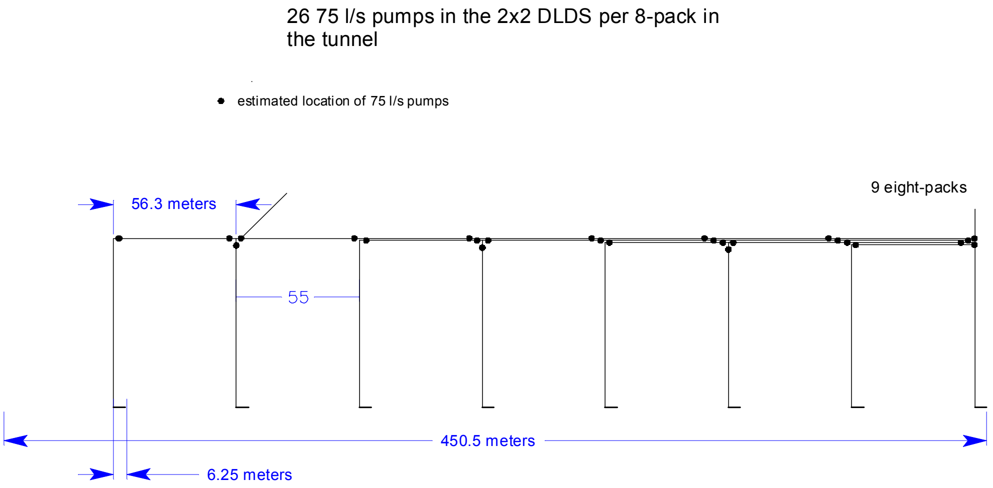

Fig. 2.3: Clustering of 75 l/s Pumps – Main Linacs DLDS

2.2 System Control: The overall pumping system can be controlled sector-by-sector from the dedicated system of bulk power supplies. Each sector is isolated from its neighbors by valves and can be pumped independently. However the RF waveguide, starting from an isolation valve per pair of klystrons, is integral with the beam pipe. The volume of pipe is dominated by DLDS. Therefore pumpdown will be efficient only if the pump volumes are well matched to the structures and distance from the roughing pumps. This is why the DLDS pumps appear clustered unevenly in Fig. 2.3. Assuming good matching, the low voltage supplies can be increased in voltage slowly to provide maximum pumping efficiency as pumping progresses. The sagging voltage characteristic keeps power dissipation under control while delivering maximum current at high pressures.

2.3 System Readback: The current delivered to each pump will be independently monitored. (Pump temperature will also be monitored separately.) Current is a reasonably accurate indication of vacuum assuming a healthy pump. Erratic currents indicate either a faulty pump or a vacuum leak. The current proposal is that each pump current is read back via a data readout card in a TEE. These data are taken to the sector alcove and fed to the main control computer for history logging and overall system control. The control system can be configured for individual sector control during pumpdown.

2.4 System Protection: Protection of the vacuum system consists of monitoring vacuum and temperatures and taking action if out-of-bounds reading occurs. Besides pump currents, redundant ion gauges near the valves are configured in a 2/3 voting logic to trip valves if a vacuum fault occurs, to isolate the sector from its neighbors. Any trip immediately shuts off the beam. These gauges are read out at the sector near or inside the valve controller so protective action can occur even if the main control system is not functioning. The main control system can add another layer of machine protection by monitoring all valves and gauges and executing a redundant protection routine.

3. Technical Issues

3.1 Radiation Hardness: The electronics that is not behind ~2 ft. of concrete shielding must be radiation hard. In our current model the one vulnerable solid-state component is the ~5kV diode that sits directly on every pump. This may need to be protected in some way to work at all because many pumps are physically right on the structures, inches from the beam. If a solution to this problem is too difficult, an alternate solution is to rectify the voltage on small cards in protected TEEs and transmit 5kVDC over short radiation- hard jumpers (M. Browne). This implies quite a different architecture. Both alternatives will be investigated.

3.2 DC Power System: The power system may be separate for vacuum so that a system level control can be exercised over all pumps with the power supply. However, since TEEs also need DC power, an alternative is to combine the systems and drive all pumps from cards in the TEEs as mentioned above, in which case a single delivery system is sufficient.

3.3 Alternative Power System: Another alternative that needs study is to distribute 120VAC power along the main linacs and use small local power converters for clusters of TEEs. The supplies will have to be protected in TEEs of their own. In this approach any group control of pump-down will have to be done via the control system communicating to each TEE. Again, tradeoffs need further study.

3.4 Communications: The alternatives are either serial copper link or wireless. Fiber optics cannot be used in the tunnels unless protected in a min-tunnel of its own. Since the vacuum system control and read-back can be very slow, one could save communications cable if transmission of a standard robust protocol can be carried on the power cable itself. This has disadvantages in case of failure of the power system, as well as complexities of mixing highly reliable transmission onto a heavy copper rail system. Alternately, the vacuum system would be an ideal candidate for wireless control if the necessary reliability can be obtained. Some experiments have been conducted and more study is needed.

4. Discussion of Configuration Choices

The initial cost model system discussed at Lehman (May '99) was based on a well known recently completed PEP model, which was a new architecture based on modern power conversion switching technology rather than the traditional sagging linear supplies that are in common use. The supplies were rack mounted 4-channel units with 50mA per channel capability at ~5 kV. This system was completely integrated with the SLAC control and protection system. Although considerably cheaper, more reliable and better protected than the older system, the high voltage long-haul cable plant dominated the costs and reliability. Therefore in NLC a chief goal was a new architecture that would eliminate a large fraction of the HV plant. This goal was announced at Lehman and pursued ever since.

The first of two solutions is a power-supply-on-a-pump (PSOAP) model, where a radiation-hard design sits directly atop a pump, with no separate HV jumper at all. The pump module would take DC and a serial cable for control and monitoring, and would deliver voltage and pump current readout. The obvious disadvantage is the radiation hardness requirement for all components. This approach is being investigated through an SBIR.

The alternate that was developed since PSOAP was the system approach presented here, that developed out of tunnel electronics discussions. In this model the aim is to minimize the exposure of active electronics to radiation by use of the TEEs, and to take advantage of a systems approach to power delivery. The original scheme due to D.J. Nelson envisaged an overhead rail with AC power and a local step-up transformer-rectifier at the desired location. Concerns of skin-effect in the AC transmission caused a reconsideration of DC transmission and local conversion, which looks equally attractive and simple to implement. The next variant being discussed is to hide the vacuum converters in TEEs and deliver the actual 5kVDC over short radiation-hard jumpers (M.Browne).

The current program is to continue study of the alternatives and prototyping of the critical components, such as radiation-hard solutions, power conversion and read-back models.

5. References

1. *NLC Vacuum System Proposal,* D.J. Nelson, 14 April 2000, djn@slac.stanford.edu.
2. *Tunnel Electronics Status & R&D Issues,* R.S. Larsen & R. Humphrey, May 2000, http://www-project.slac.stanford.edu/lc/local/Reviews/May2000Review/Presentations/Ray-TEE%20Electronics%20R&D%20R2%20052200.pdf
3. *Possible Transformers for NLC Vacuum System,* M.J. Browne, July 2000, Word Document, mjb@slac.stanford.edu