INDUSTRIAL RESPONSE TO RF POWER REQUIREMENTS

D. M. Wilcox*, Chairman, Accelerator Industry Club, Faraday Partnership in High Power RF Engineering, c/o Rutherford Appleton Laboratory, UK[1]

Abstract

High-energy physics machine design has divided into two broadly separate directions. Today, some machines are dedicated to providing a service (light sources, neutron spallation sources, cancer therapy equipment etc.) using particle acceleration as an intermediate step. Less frequently, particle colliders are built that use the particles directly to probe the nature and origin of matter and these have developed to a point where the technology required is often at the extreme edge of what is understood let alone of what is currently achievable. In addition the scope of what industry has to supply is increasing as RF skills become scarcer. More equipment integration has to be done by suppliers than hitherto so reducing the supplier base and placing yet greater demands on those remaining.

This paper presents an industry view of some issues that arise. If industry can be brought 'inside' the project team when preparing the machine design, account can be taken of any limitations, preferences and obligations industries may have. By adopting this approach from the outset, it is more likely that projects can be completed at a lower cost, in a shorter time and with a more certain outcome.

WHAT CONSTITUTES AN RF SYSTEM?

For the purposes of this paper, the schematic diagram shown in Fig. 1 defines the scope of what is meant by an 'RF system'. The definition also includes hardware providing the DC power to drive the RF amplifier and the local control interface between the hardware and 'central control'. Designs for these elements are usually closely dependant upon the type of RF device being powered and the operating regime for the RF amplifier, e.g. pulsed or cw.

The RF system comprises

- i) A power supply
- ii) An RF source/driver/amplifier.
- iii) Monitoring and protection equipment
- iv) Passive components
- v) A local control system that provides fast feedback as well as an interface with central control
- vi) Accelerator cavity complete with RF window and RF coupler

* Manager, High Power RF Technology and Business Development, e2v technologies Ltd., Waterhouse Lane, Chelmsford, Essex, CM1 2QU, UK

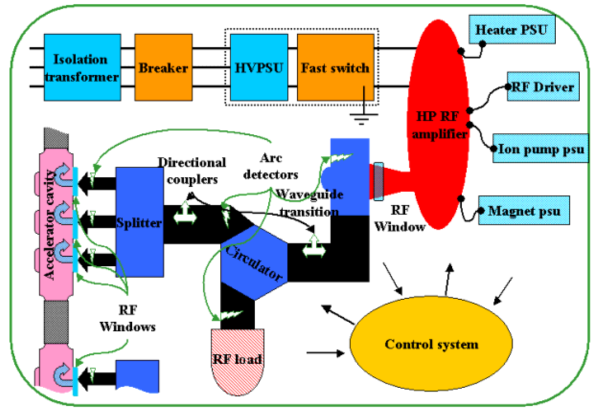

Figure 1: RF System Schematic.

Items i) to v) are increasingly being regarded as a single deliverable item. Item vi) is still highly specialised with the necessary technology residing in a few accelerator laboratories and commercial companies.

OVERVIEW

This paper deals mainly with issues raised by the accelerator community's continuing expectation that industry will be able and willing to take on the task of manufacturing unique and technically demanding RF equipment. It is not a foregone conclusion that industry will be prepared to take on the major challenges and risks that a major machine will pose. This doubt will remain until industry has acquired the necessary extra skills, processes and manufacturing capacity to be confident of success. It will also need to be confident that its investment in long-term preparations will not be rendered pointless by changes in machine technology, rival projects and political decisions.

INDUSTRY'S CONTRIBUTION TO DATE

The accelerator community has traditionally formulated its own technical specifications and relied on companies in open competition to supply its RF equipment. In general, industry has responded eagerly and the process has made sense all the while these specifications could be satisfied by capability developed by industry for its additional applications and mainstream business. For the time being, this is the process that prevails.

It is possible to avoid the cost of developing new products by using those developed for other applications either unchanged or modified to suit a specific requirement. For example, in recent years, several Third Generation light sources have been designed to use TV broadcast products, and this policy continues with the construction of DIAMOND in the UK, the Australian Light Source and others in the pipeline. Considerable savings can also be made in using other associated broadcast components. Their ready availability and multiple sourcing reduce the cost and complexity of holding spare components. The competitive nature of this business and their widespread use means that prices are relatively low.

However, machines built to study particle physics have generally required the development of a special product to meet a particular specification. Here, too, industry has consistently met the needs of machine designers. Many and varied devices have been produced over a long time and nearly all have drawn heavily on the skills and talents of industry's engineering staff.

The design and manufacture of such devices has frequently been carried out against severe time and cost constraints. Late delivery and cost over-run has been quite common and has not been good either for the customers or for the suppliers. Any manufacturing problem is compounded by the low volume and high cost of bespoke products. Difficulties with a single device on a contract for a small quantity can wipe out any profit. Nevertheless, this work has established a body of competent engineering talent and a certain manufacturing capacity that can be drawn on for future projects.

In the past, laboratories procured basic machine components and the laboratory technical staff carried out the on-site integration. There is a steady shift away from this towards the subcontracting of major sub-systems and their integration to external contractors. The traditional components suppliers are finding that they are no longer able to influence their business directly through contacts with laboratories but have to deal with systems houses. This is a major change whose impact is yet to be fully understood.

TECHNOLOGY FROM OTHER SOURCES

Not all advances relevant to accelerators have to be paid for by the accelerator community. A few particularly promising examples are being developed by industry at its own risk or are being driven by other businesses. A few examples are given below.

Power Supplies

Silicon Carbide [2] - The advent of silicon carbide active devices will make a significant impact on the design of power supplies. With the 'warm' design for the NLC in mind, high voltage, pulse modulators aimed at removing thyratrons as the switching elements have been the subject of intensive research for several years. An all-solid state pulse modulator using silicon power devices that meets the 'warm' NLC specification has been demonstrated at SLAC. The prospect of devices based on silicon carbide that have much higher voltage ratings and relatively lower power dissipation suggests that the all-solid state approach will be successful and may well be available within the timescale for the next linear collider. However, this opportunity alone will not be sufficient to justify the development of specially rated SiC devices unless the number required is augmented by a substantial additional market such as the traction or defence industry.

Intelligent, high-speed matrix converters - Research is also under way into high voltage power supplies that draw on techniques developed for motor drives. This, combined with recent improvements in nano-crystalline transformer cores, suggests that efficient, much more compact power supplies can be built. The technology is based on matrix converter techniques using soft switching, integrated power factor control and extra functionality not present in conventional power supplies. The availability of SiC devices detailed above further improves the prospects for this technology. This work is at present in its early stages but is relevant to all forms of power supplies.

Power Tubes

IOT for Fourth generation light sources - Several tube makers are looking to provide an IOT to be used on light sources like 4GLS in the UK, SASE in Germany and Cornell-ERL in the USA. There are other similar projects being proposed based on the same principle of energy recovery. The technique relies on the use of a superconducting energy recovery linac. Superconducting cavities based on the design evolved for TESLA will probably be chosen hence the 1.3GHz frequency. The RF power output required from each IOT is around 15 kW and hundreds of devices will be needed. This extension of IOT technology from UHF to L-band frequencies is not expected to be particularly challenging and indeed seems to be a perfect trade-off between power and frequency.

Gyro-Travelling Wave Amplifier [3[– This form of Gyro-TWT incorporates a helically corrugated waveguide. It has the unique capability of offering megawatt power at multi-gigahertz frequencies with good basic efficiency and up to 20% bandwidth. This new device has yet to be considered as a drive amplifier for new accelerators. It may also be useful in some fusion applications where the use of a broadband amplifier could enable mismatch to the plasma to be compensated for by changing the drive frequency

FUTURE INDUSTRIAL RESPONSE

Basic Assumptions

Every project should be expected to meet its budget and at the same time, industry must also be allowed to make an adequate profit. These need not be conflicting requirements but too often, the tender process still results in contracts that run into cost and time over-run. The fact that the cost of over-run is usually borne by the supplier is no cause for customer satisfaction. It is, rather, a step towards higher prices in the future or worse, the possible loss of a potentially good supplier from the business. Likewise, a time over-run is embarrassing for both parties. It may be due to poor contract management by the supplier but it may also imply a failure of both supplier and customer to communicate a complete understanding of the tasks involved.

Industry can be expected to participate in a project if the following requirements can be met:

- There is a realistic prospect of making an acceptable profit.
- The business is at least as beneficial to the company as other prevailing options.
- The business is positive in its long-term contribution to the company's business strategy.

However, hidden within these three statements is the question of risk. The more attractive the balance between risk and reward, the more enthusiastic industry will be. Equally, it should be remembered that a risk to a supplier is also a risk to the project.

The three points have significant implications.

First - No credible estimate of the costs and timescale can be made unless *a realistic assessment of the likely risks is made*. These are broadly of three kinds – technical, financial and commercial. The latter also includes uncertainties associated with project time frames, specifications and possible issues to do with 'who does what', the principle of 'Juste Retour' and whether the project as a whole will proceed to completion

Second - Large science contracts arise infrequently and for certain items, the short-term requirement for hardware is significant when compared to the average level of a company's production. It is a difficult matter to integrate such contracts into regular business activity without causing some degree of disruption. Problems are caused by the diversion of a significant proportion of the engineering and design staff resulting in a reduction in the level of support to regular business.

Third – Having been completed, a project's legacy to a company must be positive either in terms of profit, useful technical advancement or other benefit. This is certainly hard to determine before taking on a contract and not necessarily easy after it has been completed. It is particularly hard to establish in the case where the subject of the contract is for products that have no foreseeable alternative market and whose special technology cannot be profitably employed elsewhere.

Challenges

The challenges anticipated for the future are typified by those for the next linear collider. Whether this is a 'warm' machine or a 'cold' machine, each presents problems of manufacture that have never before been addressed. For the first time, the volume of business for some key items will hugely outstrip any presently installed capacity. The power supply and tube technology on the warm machine will be far more demanding than any currently produced commercial product of similar technology. Likewise, for the 'cold' machine, neither the great number of superconducting cavities nor the niobium metal for their production can be supplied by the world's present manufacturing capacity within a realistic timeframe. The laboratories of SLAC, KEK and DESY are leading the way in demonstrating that these devices can be built and that they work. However, the knowledge, skills, and manufacturing capacity must all be in place before any machine construction can begin. Potential contributing-countries are in varying states of readiness and in recognition of this, the UK has taken note of its relatively unprepared status and has set about remedying it. A cornerstone in this task is the UK's Faraday Partnership in High Power RF Engineering that was established some three years ago.

PREPARING INDUSTRY

In planning an international project such as the Next Linear Collider or the Neutrino Factory, there is an expectation that the nations participating in its design and final use will also benefit from receiving contracts for its construction. Ideally, the value of contracts awarded to a particular country should be in proportion to its contribution towards the cost of the machine. This is the principle of Juste Retour that has applied at CERN for many years.

The problem with this laudable aim is that it requires that each country should have industry with the capability to produce suitable product to the required value and with a quality appropriate to the application. The price must also be affordable and competitive with other bidders.

This principle is very difficult to apply effectively as it involves many factors, including local manufacturing costs. The latter depends upon the degree to which industry is involved in the pre-construction phase of the machine. This is the period where potential problems need to be identified and avoided, risks identified and mitigated, designs optimised for manufacture and contingency plans of real worth prepared. Other issues impinging on the construction and operating phases such as manufacturing capacity, training of manufacturing staff and on-going product support must be addressed and planned. Unless industry is exposed to and takes a full part in this preparatory phase, it will be incapable of fulfilling its obligations with any certainty of cost or time scales and certainly with little confidence.

This early phase is as important for industry in its impact on success as the production phase. It is in having the time to prepare in detail that industry can reduce the chances of serious manufacturing setbacks and attendant time and cost over-run. It also ensures that the hardware embodying years of design work is the best that can be achieved. The work that industry carries out in this pre-construction phase is not universally recognised as an integral part of the overall project and therefore is not considered for support in the same way as the theoretical design.

It is not valid to argue that a company can recoup costs incurred during the pre-contract phase by pricing the deliverable hardware appropriately because,

The timescales are in general too long
The risks attaching to a project such as this are too great
The competitive situation renders it impossible

Unique machine components, specialised processes and equipment need careful designing, prototyping and refining for routine manufacture. Such work needs to be completed satisfactorily and thoroughly tested if the machine itself is to be a success and it takes considerable time and resources and can be very costly. Logically, this work and its funding should be part of the national contribution to the overall project.

If the principle of Juste Retour is to work, the support that each nation provides to its industry to ensure that it can contribute to the construction of a machine should be harmonised or at least so organised that companies among the participating nations are treated equally.

CONCLUSIONS AND RECOMMENDATIONS

The next generation of light sources will be well served by industry as far as RF provision is concerned but an increase in manufacturing capacity for superconducting cavities will be needed. In the absence of any other commercial requirement the accelerator business will have to pay for this extra capacity.

The major risks associated with supplying cutting edge products into the accelerator business should be generally recognised. Industry cannot be expected to take on these risks without some considerable level of support and reassurance.

The Next Linear Collider represents a tremendous challenge for industry to supply components in the volume and quality required. A sober assessment of what this challenge represents must be made before the investment in manufacturing plant is made. The scale of the initial klystron requirement for the warm machine and its on-going demand for spares is such that the construction of a dedicated manufacturing plant co-sited with the machine could be a serious option.

New developments for other business areas will have a beneficial impact in the accelerator industry. However, if new applications for super power devices can be found, it would also make the business substantially more attractive.

Industry should have a strong input into the preparation of cost estimates for funding requests. The budget for each aspect of construction should be stated on the Invitation to Tender documents. This would ensure that affordable proposals are submitted without undermining competition. The construction budget should allow for the comparison of company prices from different participating countries based on 'ex-works' costs as is done by CERN. The variation of transport and insurance costs for large items can represent a substantial percentage of the total price if shipped over a long distance and especially by air.

Finally, there is a strong case for establishing the industrial membership of the construction team well before the construction phase. This could give rise to collaboration between companies for whom the allocation of tasks could be established without sole reliance on time-consuming, costly and, for the most part, ultimately counter-productive competition and wasted effort.

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