HIGHLY CUSTOMIZED INDUSTRIALIZED LINACS FOR APPLICATIONS IN SCIENTIFIC RESEARCH

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Abstract

Industrial capabilities and experience in linac design and manufacturing shall be given for the various types of scientific applications. Furthermore the process from contracting through establishing a project team and adequate human and machine resources for fulfilling the technical, schedule and pricing requirements shall be described.

INTRODUCTION

Based on customer requirements ACCEL Instruments [1] is designing and building medium energy turn-key Linear Accelerator Systems and rf cavities for scientific applications since 10 years (Figure 1).

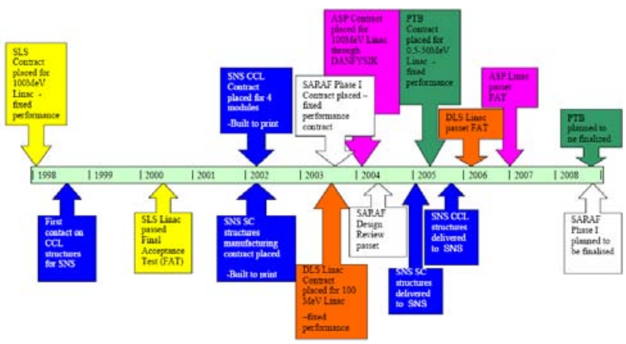

Figure 1: Timeline with linear accelerator projects.

Linear accelerators are dominated by the required rf technology in contrast to circular machines. Based on its former experience in rf technology for the scientific market [3] ACCEL could start building turn-key linacs in 1998 with the 100MeV injector linac for the Suisse Light Source [2] (Figure 2).

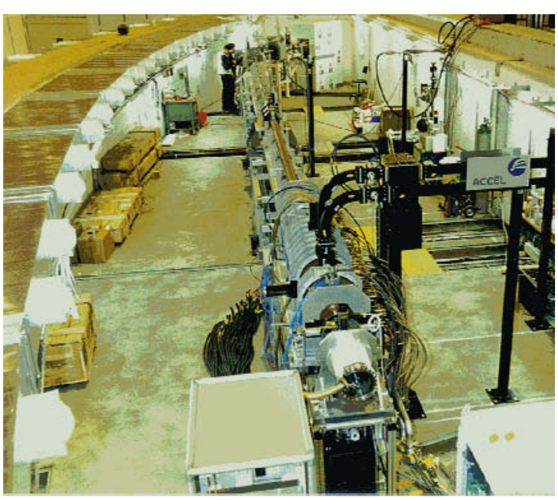

Figure 2: SLS Linac during installation in February 2000.

Starting from the different accelerator applications, within this paper it shall be shown, which resources are required to serve this special market. Beside the manufacturing and engineering skills also the necessary non productive work will be described.

SCIENTIFIC APPLICATIONS

The variety of scientific applications for linear accelerators is wide, resulting in the use of a large amount of different accelerating structures (some examples are given in Figure 3). Depending on the scientific application, particle species (from electrons/positrons through any type of Hadrons to elements as rare isotopes), particle energy, beam current, duty cycle (low, high and continuous) and other beam parameters (e.g. emittance, energy spread), the most suitable technology has to be chosen.

Analyzing engineering and manufacturing capabilities required to produce accelerating structures and their auxiliaries it can be noted that beside the choice of species, the decision between normal and superconducting technology is dominating the requirements.

Figure 3: Superconducting and normal conducting accelerating structures as required for different applications (left to right and top to bottom): SNS high beta sc structures for protons [4]; TESLA type sc nine cell structure for electrons used for pulsed (high duty cycle) and cw operation; sc CH structure used for low beta protons in cw operation [5]; nc 5.2m pulsed accelerating structure for electrons [2]; SNS CCL Module for high current pulsed proton acceleration [6]; standing wave structure for cw acceleration of electrons [7].

While the diversity of requirements can not be analyzed to derive the required resources a more general view on the different stages of those projects helps.

PROJECT PHASES

All scientific linear accelerators are designed and built to deliver a particular particle beam. Basic beam parameters are defined and result in the target specification for the linac. After the detailed specification had been derived the physics design can start to insure feasibility of the project. In order to analyze the required investment the design of the entire system has to take place. In parallel or right after that the rf design and mechanical design can be performed. Those design stages often are iterated several times at different levels resulting in basic layout, preliminary design and finally in the critical design which forms the base for manufacturing.

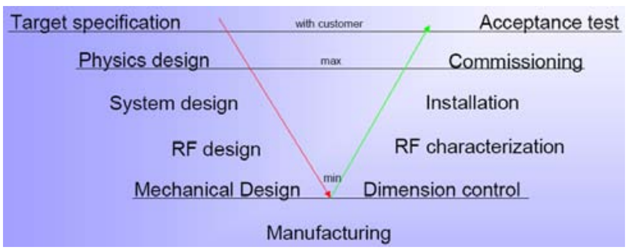

Figure 4: Project phases, from design to manufacturing and back to the system acceptance

After manufacturing the different design levels are confirmed by related test of components and subsystems. Now the sub systems are ready for delivery and installation and commissioning can take place, so that the system can show that the defined targets are fulfilled.

As an industrial partner ACCEL can serve all those stages (Figure 4), starting from the physics design, or only providing the manufacturing capabilities and produce components based on customers design.

Those extremes are directly leading to two different contract types:

- Built to print
- Fixed performance

BUILT TO PRINT

Specially large scale and unique projects as e.g. the spallation neutron source built at Oak Ridge USA, or the X-FEL planned at DESY Germany start procurement after a long project phase, allowing a detailed design and prototyping phase at the laboratories and their cooperation partners. Based on the knowledge gained hereby the laboratories are in the position to procure main components contracted to industry based on their manufacturing drawings (Figure 5) and related procedures.

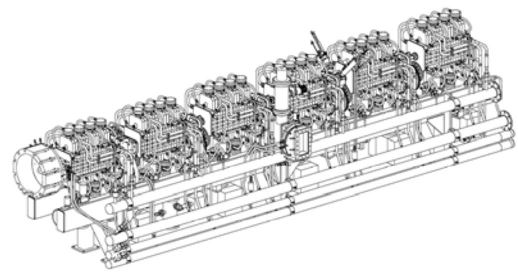

Figure 5: SNS CCL half module assembly drawing

According to those drawings a manufacturing and QA plan can be worked out and after this has been reviewed and required qualification steps have been performed the manufacturing can start.

In the case of the SNS CCL accelerating structure one segment and one bridge coupler prototype had been manufactured by LANL and the gained experience supported the industrial production (definition of "segment" c.f. Figure 6, 7)

The tuning procedures of the 14m long structures had not been established at the time of contract were developed with ACCEL's assistance at the end of the manufacturing sequence.

In a similar way the 109 SC cavities for SNS were built at ACCEL. Here ACCEL could assist with production know how mainly based on the manufacturing contracts ACCEL had from previous contracts with DESY and Jefferson Laboratory for their 9-cell and 5-cell sc cavities.

PRODUCTION CAPABILITIES

The CCL segments were manufactured out of plate material, starting with milling operations; the cavity geometries were generated using a lathe (Figure 6).

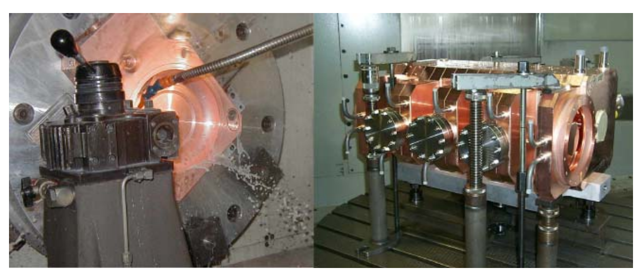

Figure 6: CCL accelerating cell during turning (left) and CCL segment after final braze on mill to get final length

Intermediate high temperature vacuum brazing steps were required. Finally the plates with all turned accelerating and coupling cells and milled coupling slots were stacked and brazed in one final step to a segment (Figure 7).

Figure 7: CCL Segment after final braze

Finally 12 of those segments connected by bridge couplers, which were manufactured using similar technologies, were mounted and aligned by the use of a laser tracker (Figure 3, middle right).

Each manufacturing step was controlled by mechanical, rf, vacuum leak and flow tests (Figure 8), to insure conformity with the requirements.

Figure 8: Leak and flow test of a CCL segment.

For the manufacturing of the SC cavities metal forming (Figure 9) and electron beam welding technologies had to be applied.

All rf structure manufacturing requires surface cleaning and preparation technologies like buffered chemical polishing, high pressure water rinsing, electro polishing and clean room mounting, all available at ACCEL.

Figure 9: Half cell after deep drawing at dimension inspection

Based on the built to print example given above main manufacturing technologies required for rf structures are:

- Turning and milling
- Brazing and welding
- Mounting and cleaning
- Testing

A detailed look shows that about 12 departments and in consequence about 40 workers are required.

FIXED PERFORMANCE CONTRATCS

As mentioned earlier since 1998 ACCEL as well delivers systems with fixed beam performance. The example given here is the proton/deuteron accelerator currently under commissioning in Israel [8], for the SARAF project.

Table 1: Main parameters of the SARAF Accelerator.

Parameter	Value	Unit
Ion species	Protons/ Deuterons	
Energy		
Phase I	5	MeV
Final	40	MeV
Current	2 (4)	mA

Based on the application here the customer defined particle species, beam current and energy as well that the system shall be capable of cw operation and that sc technology shall be used (Table 1).

With those requirements an engineering phase was launched and closely followed by the customer and international experts.

ENGINEERING CAPABILITIES

To design a linear accelerator beam dynamics calculations have to be performed first. Those calculations at a given point have to be matched with rf and mechanical boundaries, so the process is iterative and quite time consuming.

In the SARAF case ACCEL performed beam dynamics calculations, including error analysis and assumptions on halo effects (Figure 10).

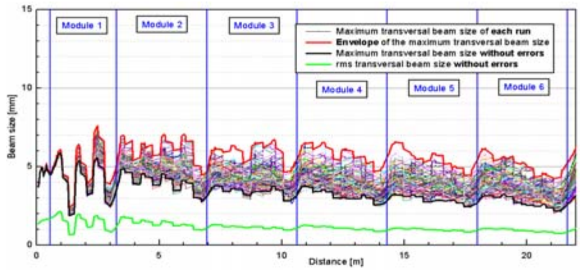

Figure 10: Beam dynamics calculations including errors.

Those calculations were cross checked by the customer with a different set of codes and results presented to the international experts for review during the critical design review.

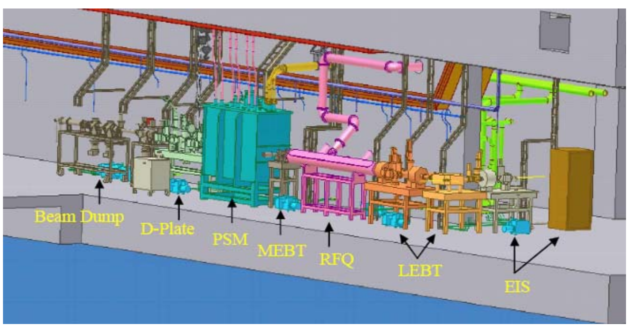

Figure 11: System layout of SARAF Phase I.

This process resulted in a system layout (Figure 11) which after passing the critical design review was converted into a mechanical design and manufactured.

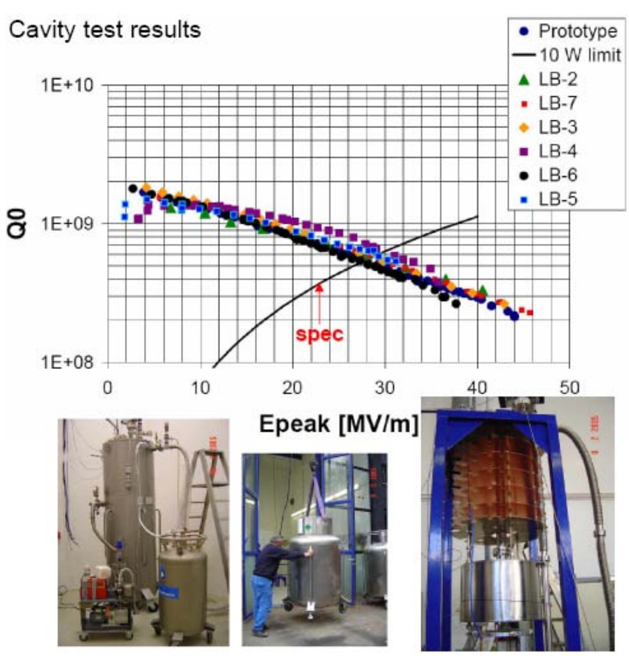

Figure 12: SARAF HWR cold tests at factory.

Prior to transport and delivery to Israel subsystems were characterized at ACCEL (Figure 12) especially all the six sc. cavities were tested individually at liquid helium temperature to confirm performance before assembly in the cryostat.

With the delivery of all sub systems a fixed performance contract typically is not finalised, in addition on site installation (Figure 15) and commissioning require an experienced team.

To design, built, install and commission a linac engineering resources for:

- Beam dynamics
- System design
- RF design
- Mechanical design
- Cryogenic design
- RF testing
- Cryo testing
- Installation
- Commissioning

have to be provided.

In the complex case of the SARAF project this result in a team of 16 engineers (Figure 13), not taken the required external experts and those on the customer side into account. Even simpler systems as our 100MeV electron injector linac still require a team of up to 10 experts in different fields.

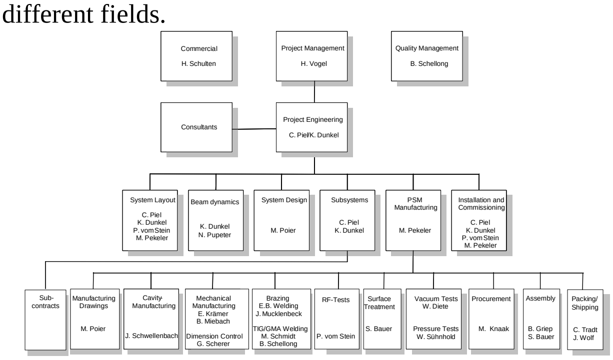

Figure 13: SARAF engineering project team.

THE WORK BEHIND THE WORK

The mentioned manpower to perform the required engineering and related obvious work are by far not sufficient. Nearly any project phase find an equivalent in “unproductive” work/effort (Figure 14).

Figure 14: Hidden costs of different project phases.

While the engineers work on the technical requirements of the request, the commercial department has to analyze the contract drafts typically provided. Administrations of some customers provide up to 200 pages with contract rules, which need to be analyzed and commented. Quite often also here external experts like local lawyers have to be included.

During the design and manufacturing phase cash flow has to be insured, which in general is handled by down payments of the customer. While those are not secured by deliverables, bank guarantees and bonds have to be provided, which beside of work as well generate costs.

The manufacturing process is closely followed by the QA department at ACCEL and often on the customer side. Required audits and certificates (e.g. ISO 9001), have to be organized and require resources.

If goods have to be transported customs and insurances have to be organized, also here taking local regulations into account is not always trivial.

Non productive work as well continues during installation and commissioning, travel arrangements have to be made and risks have to be insured.

Also on the unproductive side a couple of different experts are required. Costs related to those services and work add a substantial amount to the costs of the gods.

CONCLUSION

Since a decade ACCEL supplies linacs to the scientific research institutes world wide, for various applications. Those systems are designed in accordance with individual needs of each customer. Design, engineering and production expertise and capabilities are in house, or with qualified subcontractors.

Figure 15: SARAF Phase I installation during commissioning.

The supply of turn-key accelerating systems remains a challenge on the background of a vivid and changing market. Managing to keep expertise in house and balancing the changing workloads make this field a successful business.

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