Proceedings of The South African Sugar Technologists' Association – June 1991

STEAM TURBINE DEVELOPMENTS

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Abstract

Steam turbine power generation equipment in the sugar industry is usually of fairly simple technology, and much of it is now old. This paper shows how steam turbine technology has developed in recent years, particularly in the areas of efficiencies. Much work has gone into improving blade aerodynamics and frame size optimization to achieve this goal. Modern advanced projects in other countries and industries are illustrated, with suggestions on how these ideas in the future may be applied to the sugar industry.

Introduction

The traditional, simple rugged steam turbine is well known throughout the world, particularly in the sugar industry. Many of these designs have been in production for over 25 years. Their reliability and ease of maintenance are appreciated in industries such as the sugar industry, where reliability and availability were more important than efficiency. In some cases, the installation list for these machines has been further enlarged by the licenced manufacture of the range in other countries, such as India and Brazil.

Turbine makers would normally also manufacture a range of higher efficiency turbines which, with their increased number of stages and higher rated steam inlet conditions, were suitable for use where an increase in cycle efficiency would repay higher initial capital costs.

Background

Many industries are now aware that fuel costs are important, perhaps critical, to their economics. In recent years, therefore, some turbine manufacturers have updated their range of high efficiency steam turbines. The objective was to achieve even higher efficiencies, to accommodate higher steam inlet conditions, and to accept new technology control systems. In some cases, a modular concept has been introduced into the design.

The concept of modular construction is important. In the past, where there were a number of standard high efficiency machines, the aim now is to allow the combination of a number of proven elements based on those machines to increase flexibility. Standard modular elements would be grouped to give the best combination for each application.

Development

Modularisation

In the modular range the main turbine assembly is divided into standard modular elements arranged in a matrix so that the best possible elements can be selected, and these will combine to form an ideal solution to any given application.

Standard modular elements have therefore been created for such items as steam end cylinders, pass-through sections, back pressure exhaust ends, high exhaust pressure exhaust ends, single flow and double flow condensing exhaust ends, and bearing pedestals. A typical range is illustrated in Figure 1.

In the case of turbine cylinders the inlet end castings, back pressure exhaust end castings, and perhaps pass-through sections would be welded together before machining. Considerable experience exists in welding cylinder castings together. Such welding has the advantage that the barrel length can be adjusted so that the highest number of stages can be included. Exhaust ends for condensing turbines are manufactured from cast iron, and flanged and bolted to the high pressure end before machining the horizontal joint face.

Each module should be defined to allow patterns to be available for all major castings, permitting decisions to be made on the advanced provisioning or stocking of steel castings.

Pre-engineering and stock availability lead to significant cost reductions and reductions in delivery times. A recent 20 MWe condensing turbo-generator was delivered ex-works in just over 12 months, and was installed and ready for commercial operation within 15 months of the initial order. This is a very creditable performance for such a set.

The advantages of being able to select steam end, pass-through section and exhaust end casings to ideally suit particular applications results in better matching of the steam volume flow in each case, and results in higher turbine efficiencies and lower capital costs.

Blading efficiency

Traditional steam turbine blading in the sugar industry uses constant section low-reaction blades. In applications requiring a fairly low height, this would still be the most satisfactory blade to use. However, in the search for higher efficiencies, the development pattern over many years has been to increase the amount of steam being put through any given frame size turbine. This results in longer blades to accommodate mass flow and leads to higher efficiencies, since blade loss occurs mainly at the tip and root. The use of a smaller frame size results in lower parasitic losses.

However, as wheel diameters decrease with the use of smaller frame sizes, and blade length increases due to higher volume flows, errors in incidence angle at the tip and root of constant section blades become important, and analysis becomes more complex. In association with leading experts in the field, advanced quasi 3D flow analysis programs for the analysis of turbine stages have been developed. The result is more complex blade sections of the type shown in Figure 2. It shows the extreme change in profile over its length, with very low reaction at the root, and a tip section having a larger amount of reaction. Incidence errors are therefore reduced to almost negligible levels over the whole length of the blade.

Figure 3 shows one of the many graphic results from the flow analysis programs, and demonstrates boundary layer effects and flow patterns.

Blade improvements have been complemented by substantial improvements in manufacturing processes for static diaphragm vanes. These are concerned mainly with electrical discharge machining (EDM) methods, which have allowed complex computer generated profiles for the vanes to be manufactured. These can be used with conical shroud

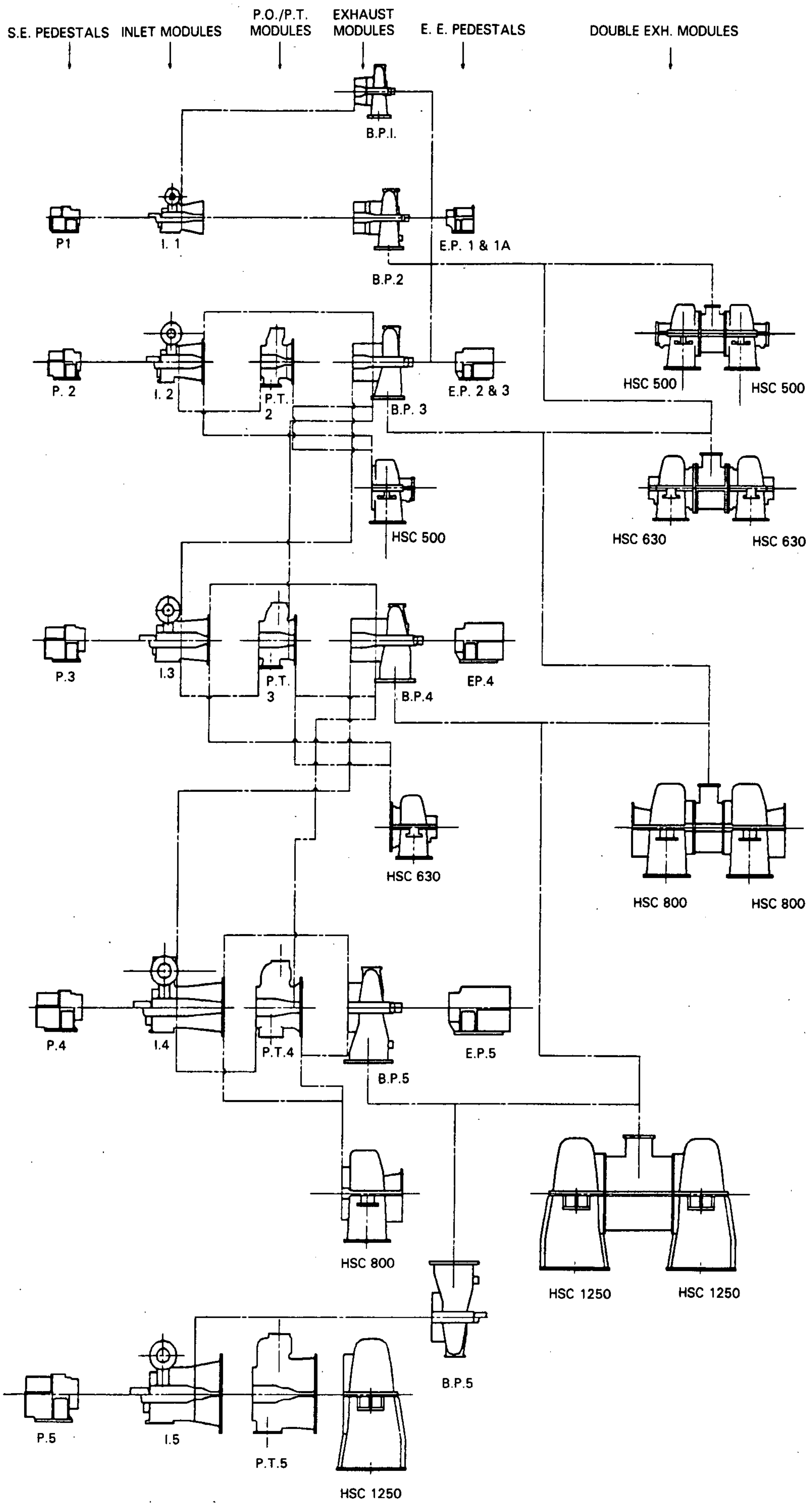

FIGURE 1: The individual elements comprising the modular range.

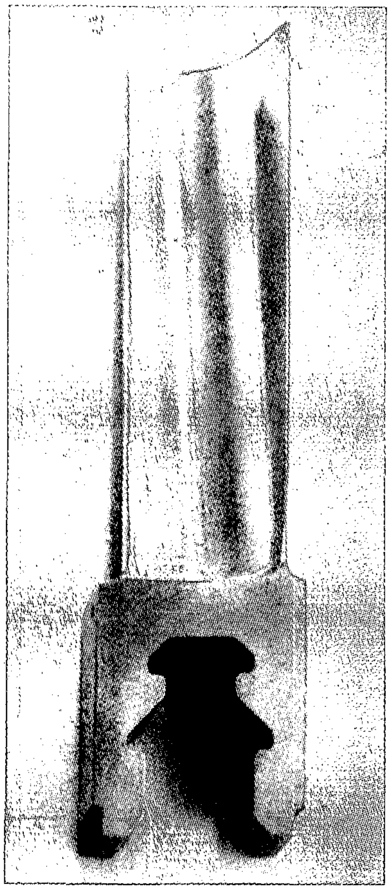

FIGURE 2: High performance turbine blade.

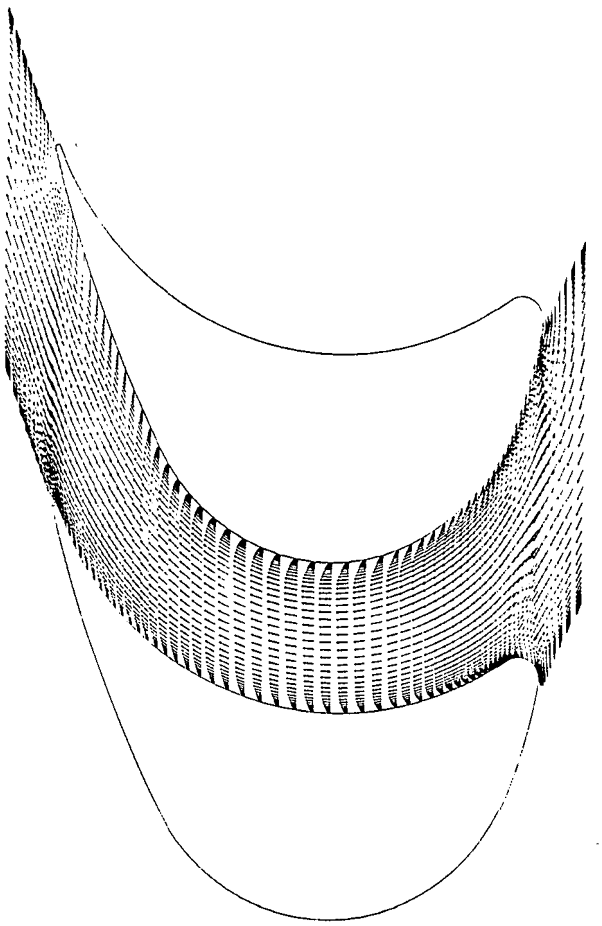

FIGURE 3: Computer generated steam flow pattern through turbine blade.

rings, having EDM apertures to position the vanes. The diaphragm assembly is completed by welding together with inner and outer plates, resulting in a rugged integral construction satisfying the advanced aerodynamic requirements.

Because of the higher reaction levels at the tip of the improved blading, more care is needed to ensure sealing any steam leakage path around the blade tip. To achieve this a standard spring loaded seal (similar to an interstage seal) and bearing are used on specially machined portions of the blade shrouding. The seal is shown in Figure 4. A clearance between seal and shroud exists during normal operation. However, should the fin touch the shroud during start up, the spring loaded feature ensures that the seal moves away from the shrouding so that no damage occurs.

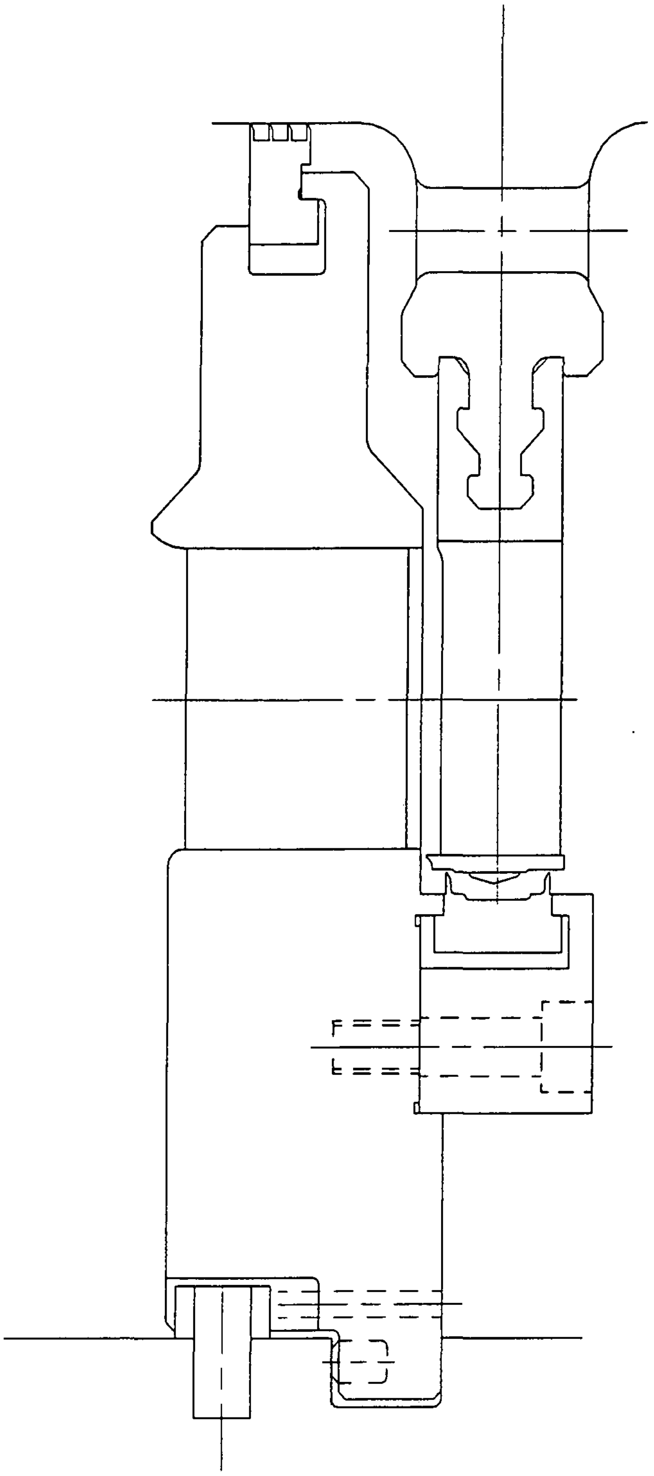

FIGURE 4: Blade tip seals.

LP condensing blading

In parallel with the development of standard blading, development of the standard LP blading for condensing turbines continues. Again, advanced computerised aerodynamic programs have been used to develop blades with 26% more volume flow capacity than their predecessors, resulting in larger output within a given modular frame for given exhaust conditions, or efficiency gains by reduced leaving losses.

In association with leading experts, computer programs are used for determining blade natural frequencies, and the modern LP blades for power generation turbines run freestanding. Advanced finite element computer programs for stress analyses have been developed to determine changes in twist which occur with large blades under running conditions.

Direct computer links allow data for blade sections to be transferred from design departments to remote machining factories. Links can be used as direct inputs for computer controlled multi-axis milling machines, allowing the blade forms to be made.

More advanced blades are now in service, and their performance has equalled or exceeded all predictions. The progressive development of LP blades continues.

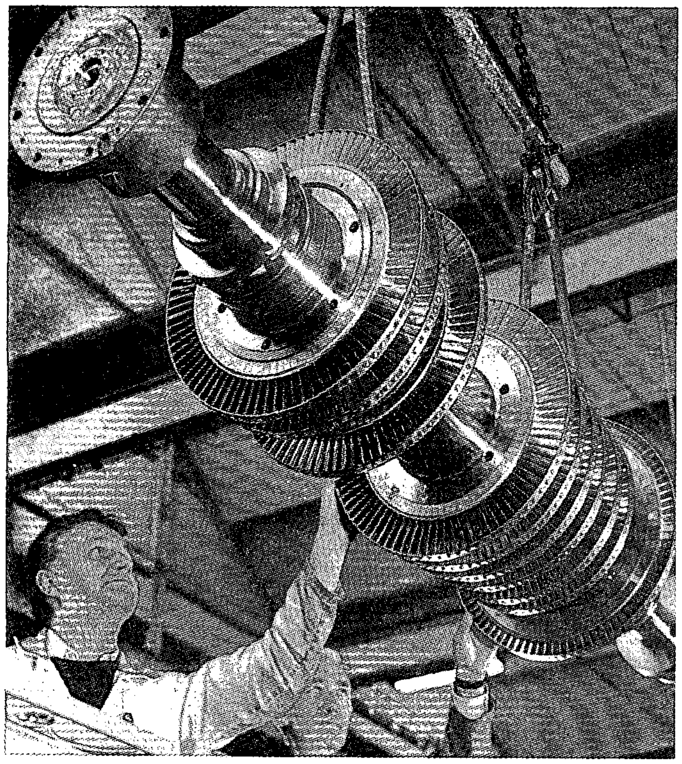

FIGURE 5: Pass-out back pressure turbine rotor with high performance blading.

Twin cylinder turbines

With condensing turbines, the last row blading is the most technologically demanding portion of the design, and therefore always receives first design consideration. Once an exhaust end blade and its associated blade root have been designed, there will always be a maximum rotational speed for the blade, due to blade root stress limitations.

This maximum rotational speed can lead to compromises being made in stage design at the HP end of the turbine. If wheel diameters are made relatively large, blade heights will be very small. Low blade heights are inherently of low efficiency, due to losses at root and tip. Alternatively, wheel diameters can be made smaller, resulting in taller blades for a given annular area, but any advantage is offset since the blade speed is then much too low.

The critical nature of efficiency levels has recently been highlighted in the UK by the advent of high tariffs on exported power for non-fossil fuel generation. The result is that the increased capital cost of the turbine is more than justified by an increase in generated power. In some applications therefore, a double flow exhaust for condensing turbines incorporating standard available modular exhaust elements has been used (Figure 1).

This arrangement results in being able to use higher rotational speeds for any given exhaust volume flow capacity. Gains in efficiency of the HP turbine (producing 66% of the power) are substantial, due to higher running speed and taller blades. Furthermore, a higher number of stages can be employed (typically 19 or 20), compared with a single cylinder machine (typically 11 or 12).

This arrangement recently has been successfully used in Europe for district heating schemes, where high efficiency levels have been essential.

Control systems

Modern modular turbines have control system components arranged to make provision for electronic governing systems, pressure control systems, overspeed protection systems, etc., which can be supplied. Control valve assemblies are arranged in a straight line across the top of the turbine. This allows a single power amplifier to be used to lift all the valves through a simple mechanical linkage.

The single amplifier uses medium oil pressures (25-30 bar) and control oil pipework is kept to a minimum. Control oil is supplied by motor driven pumps, simplifying the turbine installation. Emergency shut down of the control valves is through duplicate solenoid valves, which are arranged for on-line testing.

Electronic control systems have simplified the auxiliary drive arrangements associated with previous generation hydraulic governors, in that the steam end bearing pedestal contains only journal bearing and thrust bearing, together with the magnetic speed pick-ups for governor and overspeed trip.

Electronic control systems for every conceivable use are available from many manufacturers around the world. An electronic governor has been developed which is particularly stable in operation, due to its electrical load sensing circuits, which allow it to anticipate changes in speed resulting from load changes, and to make adjustments to the turbine control valves before any speed change results.

The final conversion from an electronic signal to a mechanical force is carried out in a proprietary electronic input hydraulic actuator. The resulting system is of very high performance, and is simple to install and maintain.

Remote controls can also be provided to open the combined stop and emergency valves during starting. The controllers allow convenient interfacing with a comprehensive automatic starting controller which can also be provided. The system can be arranged to control the complete run-up sequence through to automatic synchronising and the application of load.

Application

The traditional turbine, as used in the sugar industry, remains a low cost option for industries where abundance of free fuel has traditionally led to a need for rugged, simplified

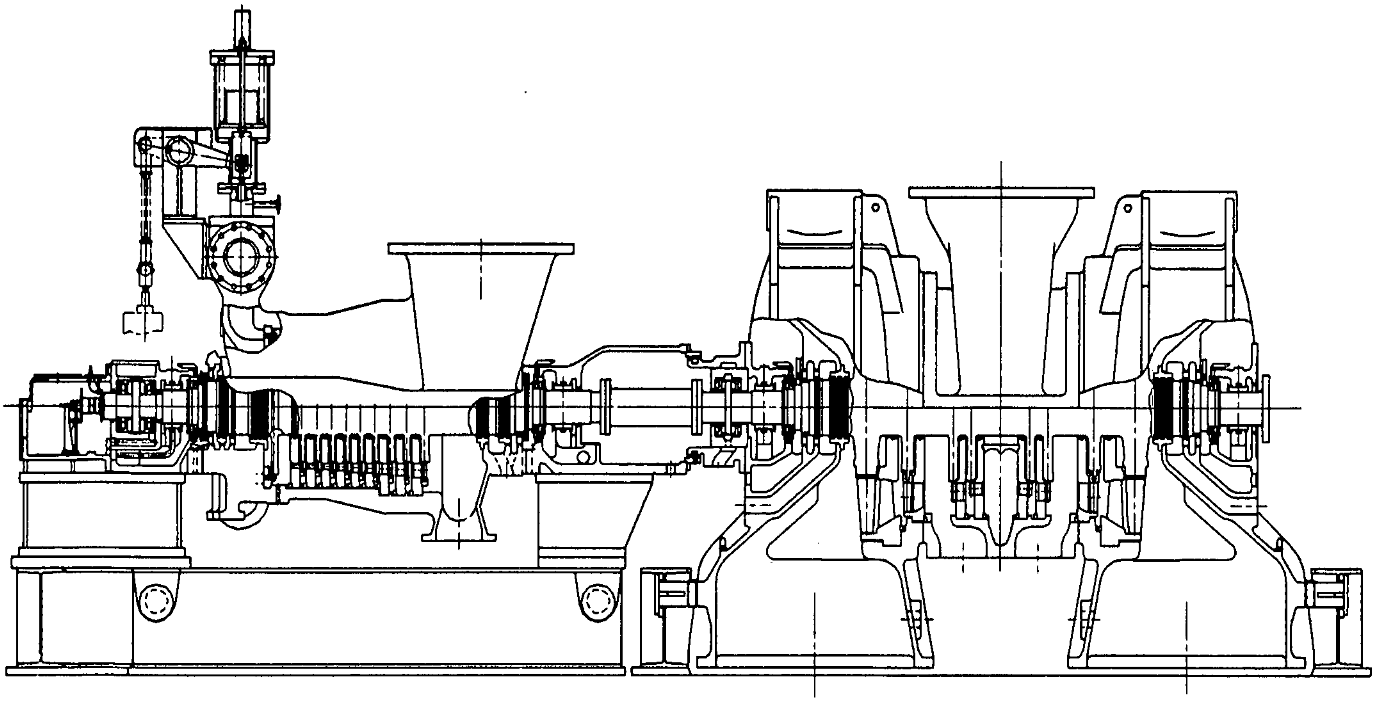

FIGURE 6: High performance twin cylinder steam turbine.

designs rather than high efficiency units. However, such applications are becoming increasingly rare due to the realisation throughout the world that any fuel is a valuable commodity, not only for financial reasons, but also because of world wide concern for the environment. Many enterprises are now evaluating the economics of using locally available fuel in the most efficient way possible to maximise power generation.

In the UK the advent of the Non-Fossil Fuel Tariff for specially selected projects using 'renewable' energy sources has resulted in many interesting and diverse projects. One such project located at Eye in Suffolk will burn chicken litter from battery farms. The fuel will be collected from a radius of 20 miles around the power station, and will be delivered in lorries at the rate of 20 tons per hour. The economics of the project demanded a turbine of the highest efficiency possible. An order was placed for a 14 MWe twin cylinder condensing turbine similar to that illustrated in Figure 6. The capital cost of this turbine is around 20% more than a conventional single cylinder turbine, but the improvement in internal efficiency of 8% more than compensates for the increase.

Another application which has resulted in orders for these advanced twin cylinder designs is that of the European district heating market. Efficiency was of paramount importance, and the extremely high efficiency of the design was in this case complemented by the ability to exhaust at two different pressures. Some of the flow is exhausted at low pressure, and raises district heating water from a nominal 50°C to 67°C. The remaining flow is exhausted at a higher pressure, and takes water up to 85°C in a separate heat exchanger. A larger amount of energy is thus converted to power in the turbine than would have been had a conventional single cylinder design been used. In addition to these features there is ample room with this turbine layout to incorporate any desired bleed connections for feed heating or de-aeration duties, and hence scope to maximise all possible options towards a higher efficiency goal.

The sugar industry should not consider itself immune from world wide trends towards higher efficiencies just because its fuel is free.

Turbine blading efficiencies have increased over the last 25 years, and will continue to increase with more advanced blade path designs. Higher efficiency represents an increase in electrical output of some 13-20%. In addition, use of higher steam conditions would further enhance the power generation capability of a given process steam flow requirement. Figure 7 shows the potential increase in output, relative to standard steam conditions of 30 Bar, 400°C.

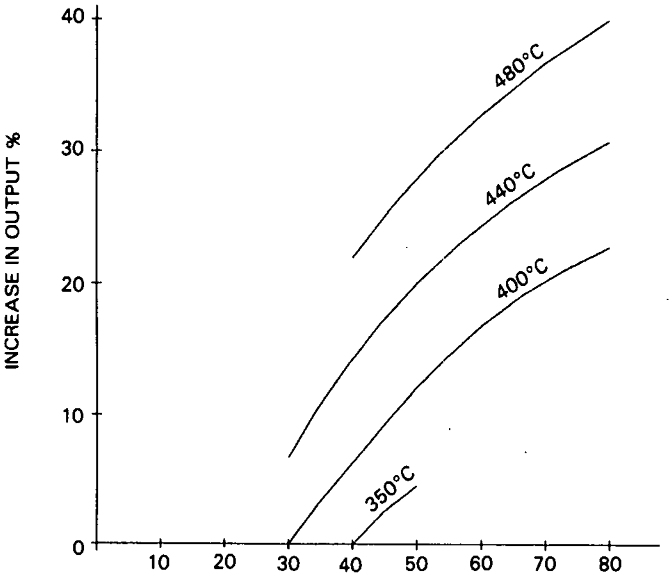

FIGURE 7: Possible increase in back pressure steam turbine output by increasing steam inlet conditions.

Any surplus bagasse could be utilised to raise extra steam that could then be used in a condensing or pass-out condensing steam turbine. An advanced scheme might use a twin cylinder turbine of the type referred to above, but with the process steam being taken from the transfer connection between cylinders. A highly efficient turbine plant results from this arrangement.

Pass-out condensing turbines are already being used successfully in sugar industries around the world to generate surplus bagasse for surrounding communities, or to provide power for irrigation during off-crop periods. This arrangement would benefit from the advanced twin cylinder concept.

Improvements in efficiency of power generating equipment is beneficial to national economies, and many countries are providing incentives to make this type of improvement. If necessary, relevant government departments should be lobbied to make improvements to local tariff structures to ensure its viability. Environmentalists are keen on any improvements of this type, and may be of assistance in effective lobbying.

Conclusion

The result of world wide interest in maximising electrical output from any available fuel, and of minimising further damage to the delicate environment of the planet, is that a wide variety of schemes is being evaluated and built. These schemes have widely differing fuel availability, operating conditions, process requirements and heat loads. These future needs can all be met through the advanced technology currently available.

Acknowledgements

I am indebted to WH Allen for permission to publish this paper, and to Mr David Beighton, Turbine Technical Manager at WH Allen, for his assistance in the preparation of relevant material.