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"40 Years of Development in Steam and Gas Turbines for Electricity Generation: Memoirs of a Turbine Engineer"

by Anthony W. Parfitt

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CSME History Committee

WORKING PAPER 5/1994

40 YEARS OF DEVELOPMENT IN STEAM AND GAS TURBINES FOR ELECTRICITY GENERATION: MEMOIRS OF A TURBINE ENGINEER

by

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Abstract

This paper is in the form of a personal reminiscence and traces the author's career as a mechanical engineer through his connection with the development of steam and gas turbine plants in the United Kingdom and Canada, including his last assignment before retirement to the Hibernia oil platform project.

This paper was presented at the CSME History Committee's Fourth Seminar, held at McGill University in Montreal in June 1994. It also demonstrates, clearly, the value that the memoirs/reminiscences of individual engineers can have for other engineers as well as for the public's awareness of their contributions to engineering and to society.

About the Author

Mr Parfitt received his technical training at the Imperial College of Science and Technology, London, England, and through a graduate apprenticeship with British Thomson Houston at Rugby. He later served with GEC (Fraser & Chalmers), and the Central Electricity Generating Board before coming to Canada in 1968, where he joined SNC Inc. in Montreal. He also spent some time on secondment to the Canatom nuclear power consortium. He retired in 1993 and now lives in Gananoque, Ontario.

Since coming to this country, Tony has been actively involved in CSME, becoming President in 1982. He is also a Past Chairman of its History Committee and a member of the current one.

About the Working Paper Series

In June 1991, the Board of Directors of the CSME agreed that its History Committee should be responsible for the production of a series of Working Papers on topics related to the history of engineering generally and to the mechanical discipline in particular. These papers may or may not be authored by members of the Committee or the Society. They will have a limited initial distribution, but CSME Headquarters in Ottawa will maintain a small supply of copies for distribution on request. These Working Papers may subsequently be published, in whole or in part, in other vehicles. But this CANNOT be done WITHOUT the WRITTEN PERMISSION of the CANADIAN SOCIETY for MECHANICAL ENGINEERING.

Introduction

Why 40 years? After all, the steam turbine was invented before the turn of the century, and the gas turbine before the Second World War. The reason is a personal one. Having recently retired after spending 40 years (1953-1993) in mechanical engineering design - mainly in the application of turbines for electricity generation - I thought I would share with you some of my experiences in the industry on both sides of, as well as in, the Atlantic. I spent 15 years in the British manufacturing and power production industries and 25 years in consulting engineering in Canada, ending with the Hibernia oil platform.

Entry to the Turbine Industry

I entered industry after graduation by serving a graduate apprenticeship with British Thomson Houston (BTH), Rugby, and - although a mechanical engineer - I deliberately chose an electrical apprenticeship. Graduate apprentices served three months in each of eight departments, and were not supposed to wander into other departments. However, I quickly learned that a drawing under one's arm was a passport to go anywhere in the shops, and thus see the whole picture. In this way I discovered the steam turbine shops, and found them of particular interest. BTH, besides manufacturing everything electrical, also manufactured steam turbines to drive their generators and compressors.

Turbine Outside Construction

On completing my two-year apprenticeship, I continued to work for BTH as a turbine outside construction engineer. This involved travelling round the country installing new turbines, doing summer overhauls and trouble-shooting where necessary. I figured that, while young and single, this was the time to get this kind of valuable experience. I visited paper mills, a sugar refinery, an oil refinery, ships, old power stations and new ones under construction. Apart from the technical experience, it taught me how to rub shoulders with all types - rough labourers, proud tradesmen, resident engineers, plant engineers, and station superintendents, not to mention bed and breakfast landladies!

A feature of BTH turbines was a Curtiss type first stage, having a double row impulse wheel with partial admission nozzles. The nozzles occupied sectors of the periphery, each sector being governed by a separate admission valve operated sequentially by an overhead camshaft. This feature made their turbines efficient at part load and very suitable for load following, but much less suitable for the high steam conditions associated with the large base load machines then under development. The need for change was not appreciated by BTH management, who tended to take for granted the turbine part of their business. Too late they built a new turbine factory at Larne in Northern Ireland, but already they were eliminated from the very competitive large turbine market. The factory became a white elephant - and, in fact, was once used to house a team of circus elephants!

Turbine Design

In 1953 I was engaged to be married and sought a stationary place of work. I joined the General Electric Company (GEC) turbine works at Erith, Kent, traditionally known as Fraser & Chalmers, as a turbine designer. It was a very small establishment, but the chief designer had very progressive ideas. At that time GEC was producing 60 MW turbines with features which would later become the industry norm. For example, instead of each rotor being connected to its neighbour with a flexible coupling, GEC used rigid couplings throughout, and a single thrust bearing for the whole assembly. Large flexible couplings were notoriously troublesome, and this arrangement contributed to improved reliability.

A new turbine shop was built and big machine tools were purchased to enable larger turbines to be produced. However, in 1956 an incident took place which could have spelled the end for GEC turbines. Two new 3000 rpm 60 MW turbines had been installed at Uskmouth in South Wales and were undergoing running tests (see Fig. 1). During excitation tests of one of the sets, the exciter of the neighbouring set was inadvertently tripped. This should have caused the tripped set to shut down automatically. However, the stop valves failed to close promptly and, as a result, the machine began to overspeed. Hearing the rising tone, the turbine driver ran towards the governor end pedestal to operate the manual trip lever but, before he could do so, the generator rotor burst. The LP turbine shaft broke like a twisted carrot and the twelve wheels split and flew through the cast iron LP casing (Fig. 2). The large overhead crossover pipes were flung round through 180 degrees, decapitating the unfortunate driver. One LP wheel flew downwards and killed a welder who was working near the condensers. Most of the wheels flew out through the turbine hall roof, some ending up in the river mud. Two of them hit the concrete block wall separating the boiler room from the turbine room and, after sawing their way through and becoming white hot in the process, ricocheted around the boiler house. The boiler house attendant, sitting drinking his tea at the time, was scared out of his wits but was physically unharmed. As for the generator, the rotor was contained within the stator.

An official enquiry ensued, very dilligently carried out jointly by the Central Electricity Generating Board (CEGB) and GEC. Every piece of the turbine was recovered and brought back to the factory. Because the Turbovisory Panel was not energised during the electrical tests, there was no record of the speed at which failure had occurred. My job was to find this out from the stretched bores of the 32 shrunk-on wheels. It was a very laborious process, but excellent corroboration was obtained. If I remember rightly, the this Figure - 36 inches long - have to be individually forged and machined to close tolerances for one expansion stage.) But, while it lasted, this period of rapid development could be described as the heyday of the steam turbine industry. There had been nothing like it before, and there has been nothing like it since. The fierce competition had its downside, however, in that the number of UK steam turbine manufacturers fell from five to three as orders became bigger but fewer.

Gas Turbine Development

In 1959 I was given the task of reviewing the possible application of gas turbines for power generation within the CEGB system. At that time the CEGB had two experimental 15 MW gas turbine generators which were not at all successful. They had been designed like steam turbines with heavy components and were complex, incorporating intercooling and reheat. In order to get a perspective on the current state of the art, I visited with two colleagues every gas turbine generating plant in Europe - about 20 in all. As a result I recommended that the two 15 MW gas turbines be scrapped and that the CEGB should concentrate instead on lightweight gas turbines based on aircraft practice. In this way, advantage could be taken of the technology already developed and paid for by defence budgets. I then went on a six-week course on gas turbine design given by Power Jets - the development firm founded by Sir Frank Whittle - at its school at Farnborough.

At that time Bristol Siddeley was pursuing other markets for their aero gas turbines and they had installed a 3 MW pilot gas turbine plant in the middle of Dartmoor for the South Western Electricity Board. This plant was powered by a Proteus turbo-prop engine adapted to drive a generator. It was unmanned and controlled by telephone from Head Office in Bristol. It proved to be very reliable and economical as a peak load unit, and so quiet that sheep grazing alongside didn't even look up when it started.

Based on this experience, the Board purchased a larger 15 MW pilot gas turbine plant, for which I wrote the specification. Built by Bristol Siddeley, it used an Olympus jet engine and a custom-made power turbine, and was installed at Hams Hall 'A' Generating Station (Fig. 5). It functioned perfectly as a peak load unit, but the irony was that the exhaust gas had a higher temperature than that of the inlet steam of the adjacent steam turbine. Theoretically there was a clear case for a combined cycle plant, but the CEGB was not ready for it. Also, it took a long time for power station superintendents to get used to the idea of aero engines running their stations. They liked the fact that these engines could be lifted out and replaced in eight hours, eliminating on-site overhauls. But the thermal efficiency of a gas turbine plant was about 27 percent - comparable to an old steam plant - whereas a large steam plant had an efficiency of 38 percent. Also, a gas turbine burned diesel oil while a steam plant burned indigenous coal or heavy oil.

With the prototype proven, the Board moved quickly to exploit the potential of aero-derivative gas turbines and in 1964 it purchased and installed 12 four-engine peak load units to fill an urgent shortfall in generating capacity. These units consisted of four Bristol Siddeley 70 MW units, each powered by four Olympus engines, four English Electric 56 MW units, and four AEI 55 MW units, each of which was powered by four Rolls Royce Avon engines, for a total of 724 MW (Fig. 6). These were all completely new designs which incorporated synchro-self-shifting clutches to enable the generators to operate as synchronous compensators with the gas turbines shut down. Within two years they were all installed and operational and, to the best of my knowledge, are still in service today.

During the 1960's electricity demand in the UK was doubling every decade and there were critical times when the whole national grid was strained. Being an island, the only electrical connection with the rest of the world was an insignificant 120 MW DC submarine link with Electricité de France. At such critical times, system frequency would decrease causing station auxiliaries to run slightly slower - having the effect of decreasing station output just when it was most needed.

To correct this unstable situation the CEGB installed with every new 500 MW steam unit a 17.5 MW auxiliary gas turbine generator that was started automatically by a low frequency relay, and this became standard practice. Now, when the system is under strain and the frequency drops below the relay setting, the auxiliary gas turbine set starts automatically and the main unit auxiliary load is automatically transferred to it. Thus the main unit output is not only maintained but is actually increased, and frequency recovers. This practice has made a significant contribution to the security of the British national grid, and on several occasions has saved it from collapse (Fig. 7).

Aero-derivative gas turbines were also used as auxiliary generators in nuclear generating stations where they also had an important role in ensuring the safe shutdown of the main plant in case of emergency. For this application they competed with diesel engines, but above a certain output diesel engines became prohibitively large.

In 1967 I was privileged to have dinner with Air Commodore Sir Frank Whittle at his private residence. He was a man with a large chip on his shoulder, but we exchanged many interesting memories - particularly as he had begun the development of the jet engine in 1937 at the BTH factory at Rugby and the nearby English Electric factory at Whetstone. But, being an Air Force engineer, he had never envisaged that jet engines would be used for electricity generation or naval propulsion.

Canada

The 1960's were an exciting period of development in the field of power generation in the United Kingdom. But I could foresee it was coming to an end and so, in 1968, I came to Canada to join SNC in Montreal. At that time CANDU was in its infancy and the Nuclear Steam Plant was being developed by AECL. Ontario Hydro was actively developing the Balance of Plant for use in Ontario. In 1969 SNC, Montreal Engineering, and Shawinigan Engineering formed a consortium known as Canatom, primarily to cooperate with AECL in developing CANDU Balance of Plant for use in other Canadian provinces as well as elsewhere in the world, and also to build heavy water plants which were a prerequisite for CANDU.

I was seconded to Canatom, and was involved in the design of the Glace Bay and LaPrade Heavy Water plants and the CANDU Station at Point Lepreau in New Brunswick. For CANDU, the 1970's was a decade of great development, and we had high hopes of selling CANDU's worldwide. In fact, Canatom won three simultaneous Balance of Plant contracts for Gentilly II in Québec, Point Lepreau, and Wolsung in South Korea. Unfortunately, once these were completed, there were no more large nuclear contracts to follow.

Point Lepreau CANDU Nuclear Plant

I spent five years working on the design of this plant, which belongs to the New Brunswick Power Commission. It is situated on a peninsula on the Bay of Fundy where the tides are among the highest in the world, and this fact had a profound effect on the design of the turbine building. It resulted in the turbine floor being at grade level and the basement being deep enough to be below minimum low tide level. The turbine foundation block is therefore unusually tall.

The 660 MW steam turbine generator is a C.A. Parsons machine rotating at 1800 rpm, with an HP turbine, moisture separator and reheater, and three double flow LP turbines. Like most turbines in nuclear stations, having relatively low steam conditions, the size of the unit is immense. This plant has proven to be very reliable indeed and, regularly, Point Lepreau is one of the top stations in the worldwide monthly availability figures published in Nuclear News.

Gentilly 2 Gas Turbine Plant

Hydro Québec operates a CANDU 660 MW nuclear plant near Trois-Rivières which is the only base load thermal plant in its system. Studies have indicated the desirability of having a separate source of power available that is large enough to supply the heat transport pumps in the event of an emergency shutdown, and also a source of peak load power which would help to ensure that the nuclear plant would remain on base load. SNC was awarded the diesel oil will be used to provide power for drilling but, as soon as well gas becomes available, it will become the principal fuel. Sound insulation is also important since the crew's sleeping quarters are only a short distance away from the units. Precautions have been taken to guard against seawater spray or stray pockets of gas entering the air intakes. In case of fire, the gas tight acoustic enclosure surrounding the gas turbine will automatically fill with carbon dioxide.

Conclusion

Very few mechanical engineers get closely involved in both steam turbines and gas turbines. Traditionally, these are separate fields of endeavour with different modes of thought. The steam turbine, first developed for marine propulsion, is a tremendously robust machine which will run day and night with minimal attention, and has been developed to the limits of both size and efficiency. The gas turbine, developed for aircraft propulsion, has come to be no less reliable, and features light weight and thermal flexibility.

The introduction of cooled high temperature blading has permitted a quantum leap in gas turbine thermal efficiency. At last the potential of the combined cycle is being realized, in which the virtues of steam and gas turbines are combined, making possible thermal efficiencies of 75 percent or more. This is a major improvement, compensating for the inability of the gas turbine to burn cheaper fuels such as coal and Bunker C oil. In Europe, considerable progress has been made in developing heavy oil-burning gas turbines of the industrial type. However, nowadays, stricter environmental regulations force utilities to burn cleaner, more expensive fuels and hence the combined cycle, high efficiency plants have become very attractive. In the USA, really large industrial type gas turbines have been developed which use the cooled blades now common in aero gas turbine technology, so that the gap which has existed for so many years between large steam and aero gas turbine technologies has finally been closed.

The single shaft gas turbine cannot overspeed, because the compressor (which consumes two-thirds of the turbine output) forms an inherent brake. This does not apply, however, to a two shaft gas turbine in which the power turbine could run away but for its overspeed trip gear.

Today, every time we fly, we trust our lives to two or more gas turbines, comfortably insulated from their roar. They are indeed a source of awe. Nevertheless, the large steam turbine remains one of the wonders of the modern age - and a triumph of mechanical engineering. Its power is prodigious, but to the average person it means nothing. It does not chug or roar, it merely hums. And the steam turbine generator - rarely seen by the average person - is the true heart of most modern cities. Without it, life would come to a halt. To the engineer, the sound of that huge machine steadily humming in near perfect balance is a source of tremendous satisfaction. But he must never allow it to lull him into complacency.

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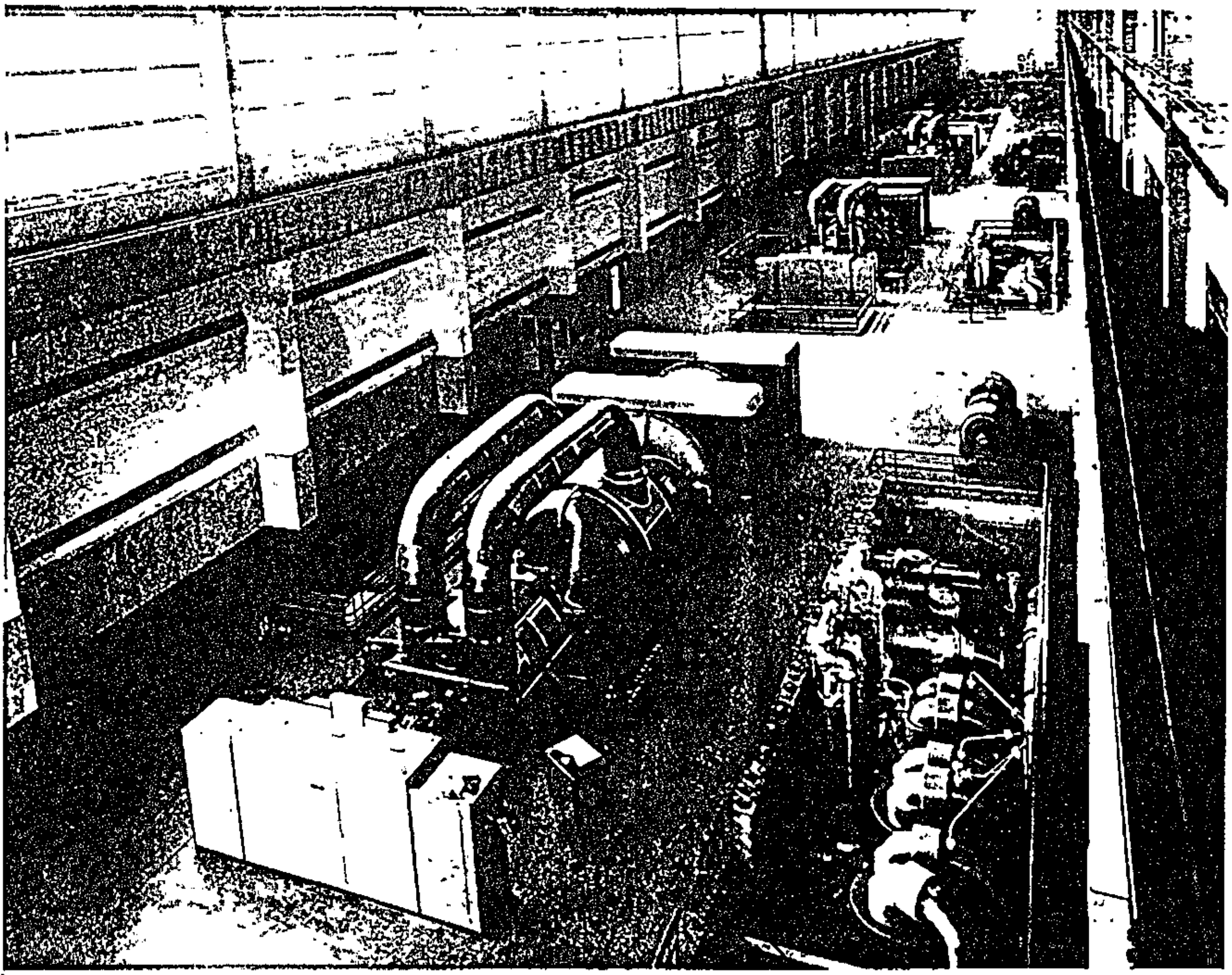
+++ Editor's Note:
The reference made by Mr Parfitt is to: 'Failure of a 60-MW steam turbo-generator at Uskmouth power station' by A.L.G. Lindley and F.H.S. Brown, Proc. Instn. Mech. Engrs. 1958 172 (No 17) 627. The story - based on the Lindley-Brown paper - has also been told by R.R. Whyte in the I.Mech.E. publication Engineering Progress Through Trouble, pp 63-70 (1975).



USKMOUTH 6 SETS 60 MW

BRITISH ELECTRICITY AUTHORITY

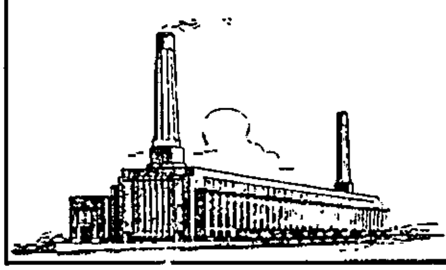


FIGURE 1

Fig. 2. General View of Damage to Turbo-generator at Uskmouth

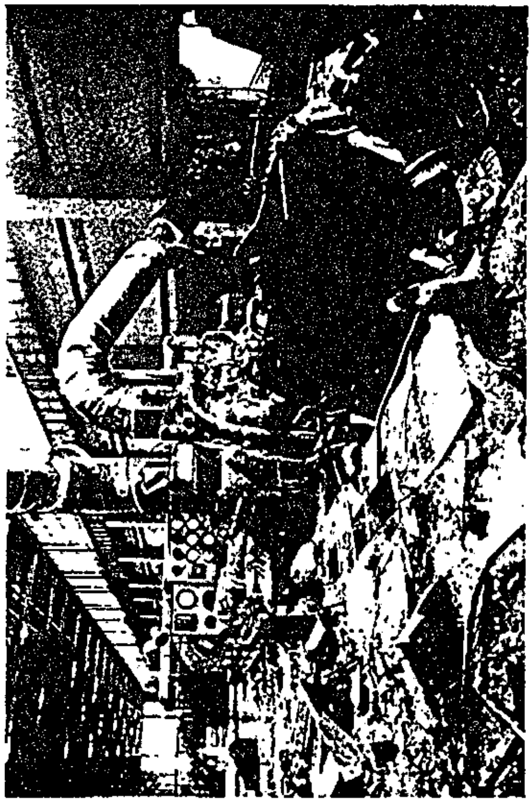


Fig. 6. View showing Fractured High-pressure Turbine Shaft

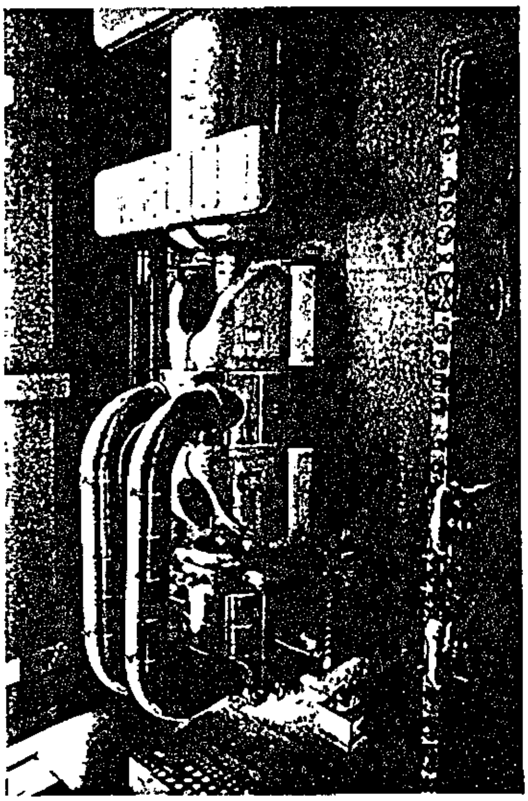


Fig. 1. 60-MW Turbo-generator

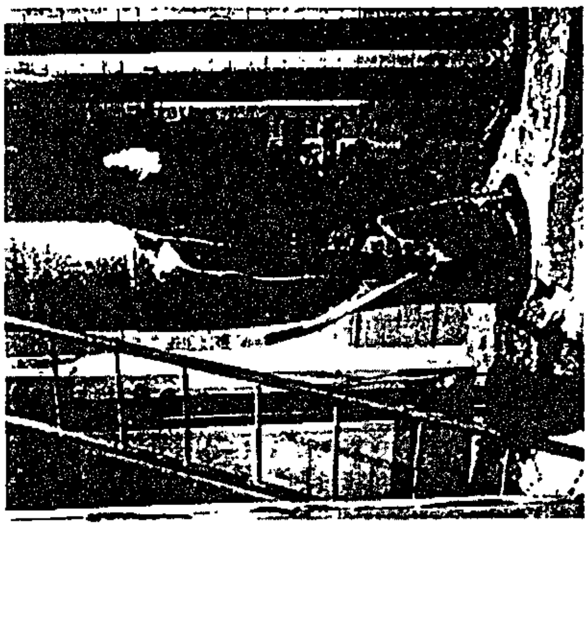
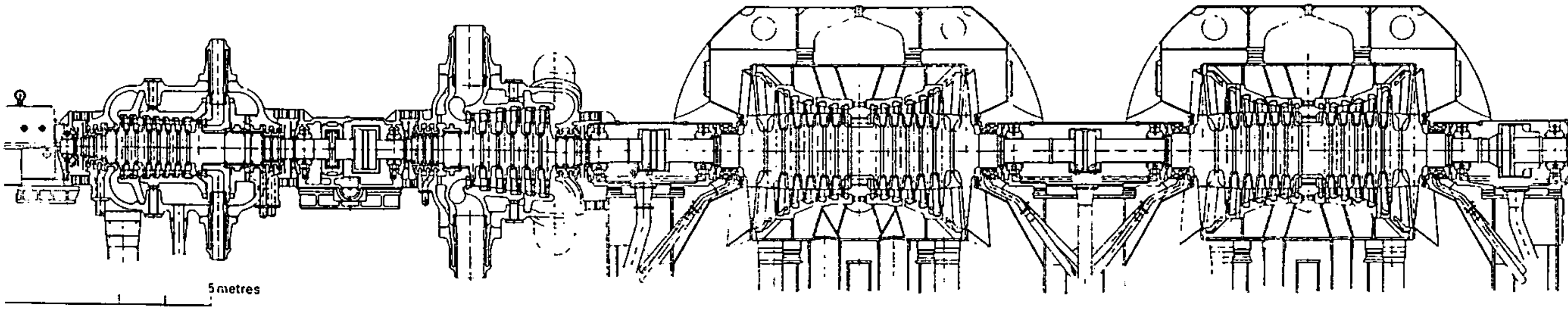


Fig. 5. Damage to Turbine Room Wall and Atmospheric Exhaust Pipe

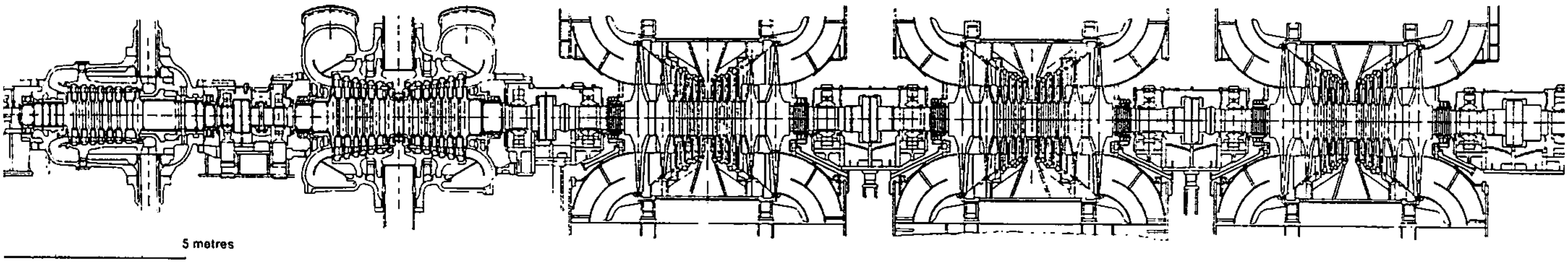
[I.Mech.E., 1958]

FIGURE 2

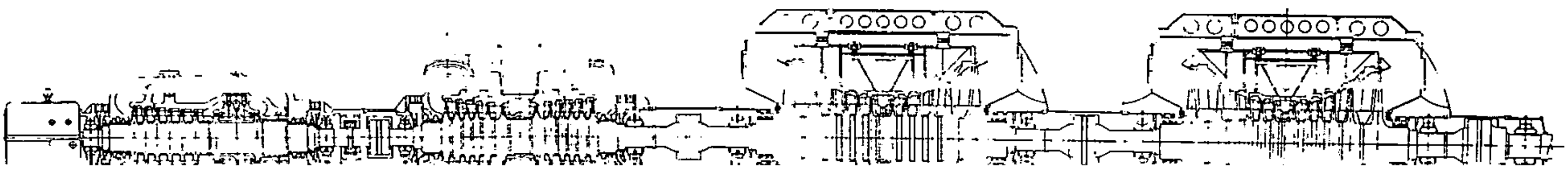
FIGURE 3

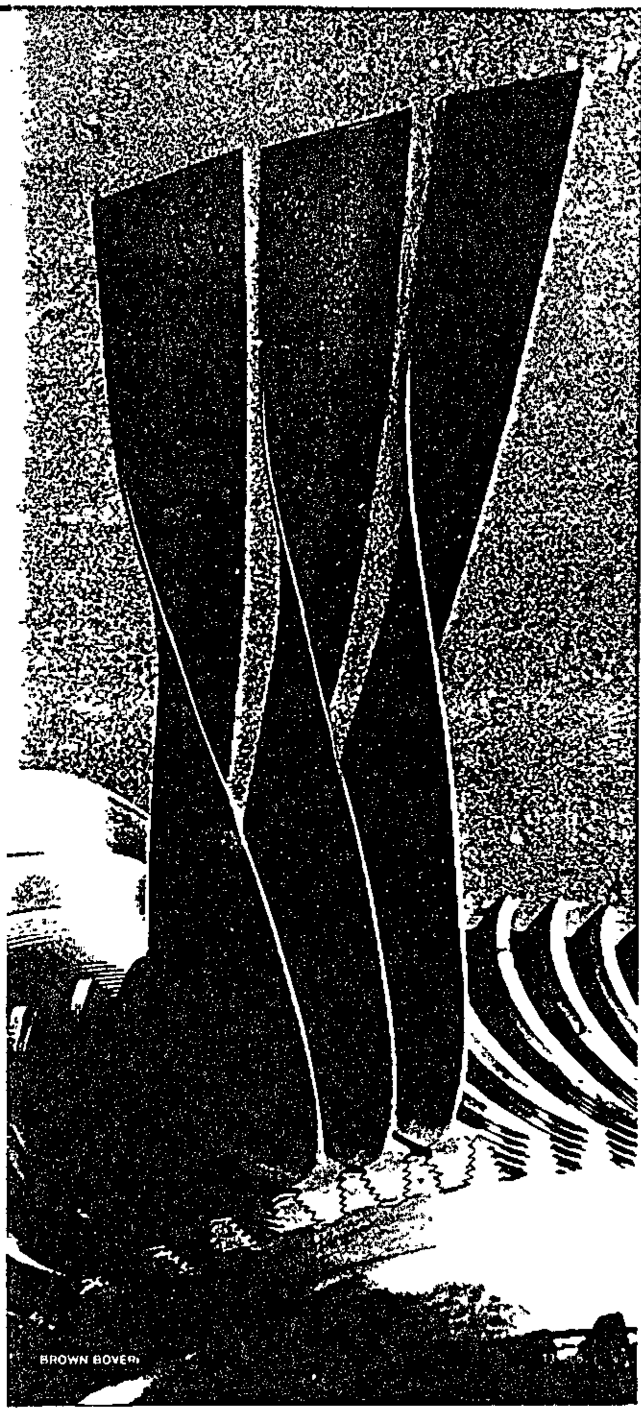


A *3000 rev/min 400 to 500 MW reheat turbine*



B *3000 rev/min 660 MW reheat turbine*





Blades of the last moving row
in a 600-MW reheat turbine
(Photo: Compagnie Electro-Mécanique. Paris)

FIGURE 4