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69,000 KW FRANCIS TURBINE FOR SHIMOTAKI POWER STATION, TOKYO ELECTRIC POWER CO., INC.

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I. PREFACE

The Shimotaki Power Station, Tokyo Electric Power Co., is an underground power station newly established under the electric power development scheme of the Kinu River, a large tributary of the Tone River.

The site of the power station is well-known as the Kinugawa hot spring center. Along the up-stream of river, being favored with abundant water resources, electric power development has been undertaken since early times, and now plays an important role as one of the large sources of electric power in the Kanto district.

The present power-augmentation work began in 1958 ; the constrution of the multi-purpose Kawamata Dam was undertaken by Ministry of Construction after the completion of the Ikari Dam in 1956. Built for flood control, irrigation and power generation, It is a dome formed arch dam harving a height of 118 m and a storage capacity of 87,600,000 m^3. The water used for power generation is taken directly from the reservoir of Kawamata Dam and projected to the Kawamata Power Station, from where discharge water first flows into the Kuriyama Power Station ; next into the Shimotaki Power Station, and finally into the Shioya Power Station where we are supplying the hydroelectrical equipment.

These four power stations have special features as a perfect peak load station which is provided with a storage reservoir and a regulation pond respectively, and three power stations, excepting the Kuriyama Power Station, adopt an under-ground system from geographical and economical viewpoints. It is truly remarkable in our history of hydro-electric development that four generating plants should be under construction at the same time.

When these power stations are completed, the maximum output will be 205,200 kw, which not only meets a full electric demand in Tochigi Pref. but will provide excess power to transmit to the Kei-hin District.

Our Company has in the past supplied many record-making products in Japan, such as 68,900 kw vertical shaft 4-nozzle Pelten water turbines for the Wadagawa No. 2 Power Station, Hokuriku Electric Power Co., 43,800 kw Kaplan turbines for the Oyodogawa No. 1 Power Station, Kyushu Electrict Power Co., 19,200 kw vertical shaft Deriaz type reversible pump turbines for the Kuromatagawa No. 2 Power Station, Electric Power Development Co., etc. We have now accomplished the largest capacity Francis turbine, having an effective head above 300 m in Japan.

For manufacturing the present record-making water turbines, our most up-to-date techniques have been adopted. We take this opportunity to introduce to you the constitution and special construction features of the machines and relative apparatus.

II. OUTLINE

The specifications are as follows :

Number of unit :	2
Type :	Vertical shaft spiral Francis turbine
Output :	69,000 kw
Net head :	330 m
Discharge :	24 m^3/s
Speed of rotation :	500 rpm

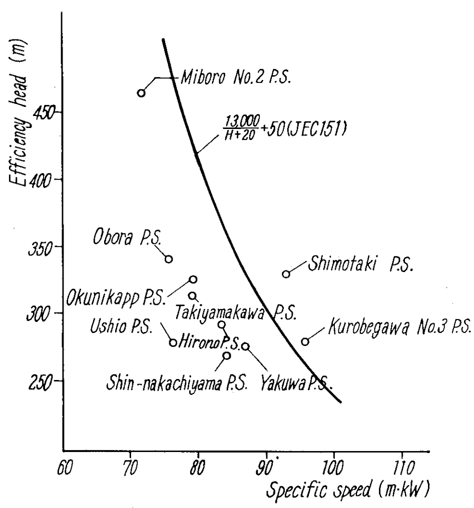


Fig. 1 Relation between specific speed and effective head

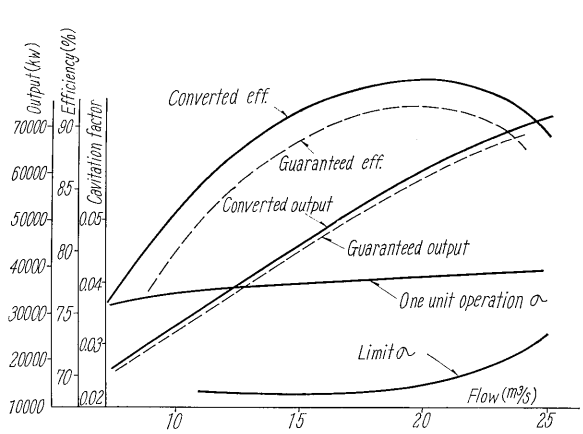


Fig. 2 Result of model test

Because of its high speed and large out-put, the turbine and generator were carefully discussed when deciding the speed. A 500 rpm plan was finally adopted after it was found to be more advantageous in raising efficiency and saving weight than 428.5 rpm. Increased draft height would have meant an increased excavation cost, which was out of the question in this under ground power station.

The specific speed is 93 m·kw which is about 7% higher than the limit of JEC 151. *Fig. 1* shows the relation between specific speed and effective head for high head Francis turbines ever manufactured in Japan.

Our system requires no pressure regulator: as a result of hypothetical discussions on turbine, generator and penstock, $\Delta p \doteqdot 30\%$, $\Delta n = 40\%$ were assured GD^2 of generator.

III. MODEL TEST

Before manufacture, model tests were carried out by a model having a runner outlet dia. 350 mm.

The test heads were 4.5 m at efficiency test and 60 m at cavitation test. By these tests, it was confirmed that both efficiency and performance of cavitation had a sufficient allowance against the guaranteed figures.

Fig. 2 shows the results of efficiency test and cavitation test. *Fig. 3* is a photograph taken during efficiency test.

In this power station, the draft head is minus, amounting to $Hs = -6.6$ m when operating 2 units at maximum output, so that air supply to the runner lower part when over load and partial load comes to question. Therefore model tests for the air supplying device were carried out, where it was confirmed that if the form and position of air pipe were adequate sufficiently natural air suction could be obtained, thus preventing vibration of draft tube.

Fig. 4 is a photograph of the air pipe undergoing test; *Fig. 5* shows a test result converted into the actual machine, where Hs' = draft tube height based on position of air pipe, ΔHap = pressure drop at edge of air pipe from static pressure of tail race at altitude of air pipe; accordingly $\Delta Hap < Hs'$ is the condition enabling natural air suction. It can be understood by *Fig. 5* that natural air suction is present under 50% opening even when operating two units.

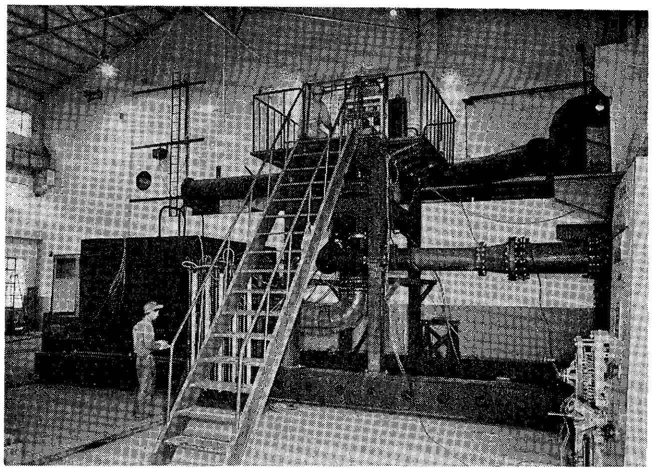


Fig. 3 Model efficiency test

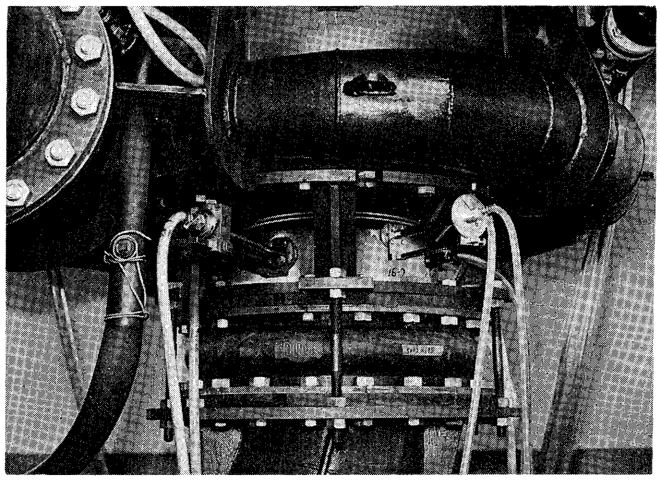
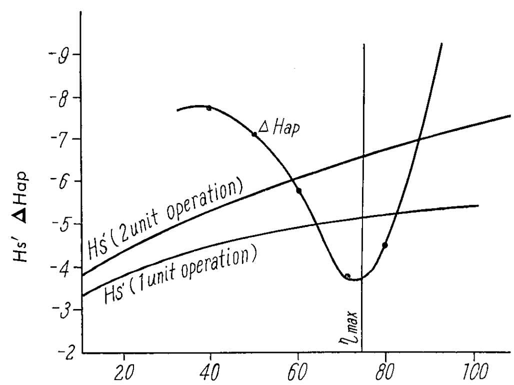


Fig. 4 Airpipe test



Hs'(m) : Draft head based on air pipe position
ΔHap(m) : Pressure decrease of air pipe end

Fig. 5 Result of airpipe test

IV. CONSTRUCTION OF EACH PART

The installation system for turbine and generator is a concrete embedded barrel single floor system as shown in *Fig. 6* and *Fig. 7*. *Fig. 8* shows temporary assembly of turbine itself at work shop: main body size is comparatively small because of high head and high speed. However, special consideration was given to its strength; also, various ideas and new systems were incorporated.

1) Casing itself is welded fabrication, great caution being taken as to materials and welding techniques.
2) Main bearing adopted an oiling system involving a viscosity pump, utilizing rotation of turbine shaft and oil groove installed in bearing itself.
3) Bearing oil tank, being different from the conventional construction, has a single inside wall to simplify the bearing part and also lessen the bearing inner diameter.
4) Rotary valve was adopted for the inlet valve.
5) Fuji electric speed governor was adopted for the governor.

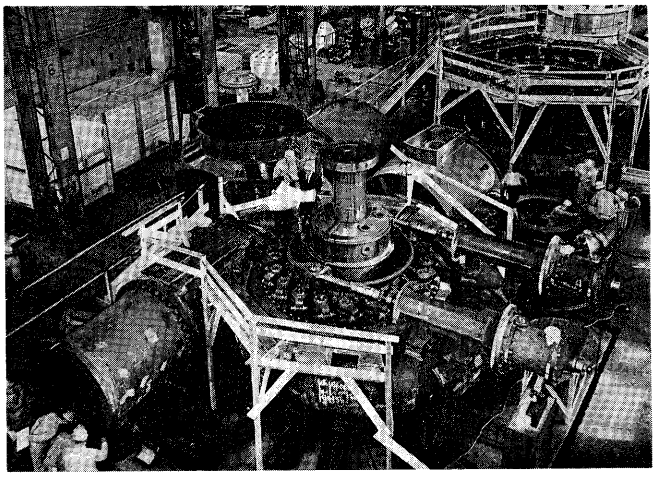


Fig. 8 Temporary assembled turbine

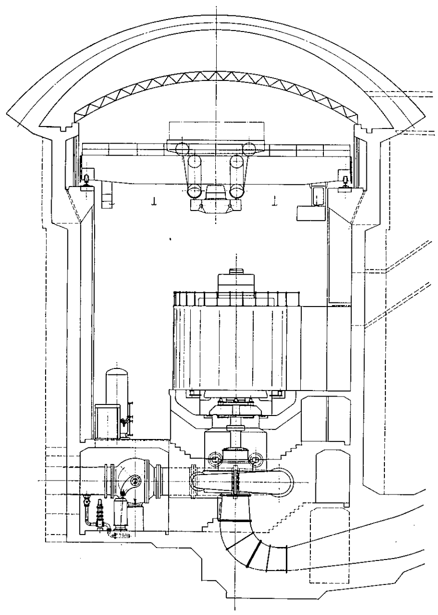


Fig. 6 Machine arrangement (section)

The above are the special features of the present equipment, however, special considerations were given to other items, details of which will be explained in the following.

1. Water Turbine

The construction is shown in the sectional drawing of *Fig. 9*. It is constructed of a welded combination of cast steel and steel plate, which saves cost, raises the safety factor, against high hydraulic pressure.

The casing inlet dia. of 1600 mm is divided into 4 sections of welded steel plate. The hydraulic pressure test value is 62 kg/cm^2, so the thickness is necessarily increased to withstand high pressure; the stay vane required a thickness of 120 mm.

Absolutely accurate welding was required, so sufficient discussion and inspection were given the welding work.

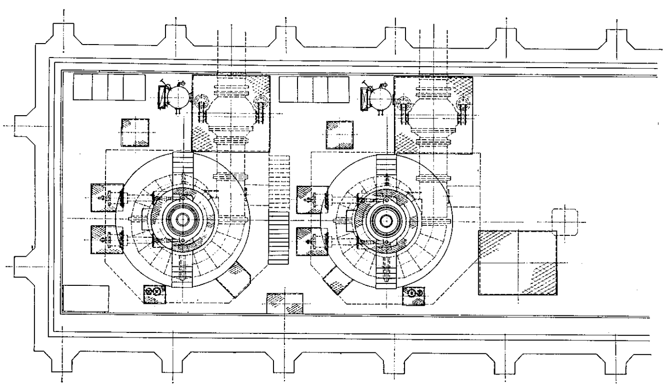


Fig. 7 Machine arrangement (plane)

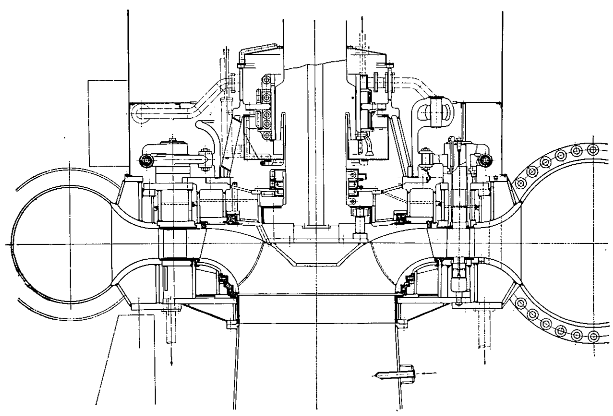


Fig. 9 Sectional view of turbine

For the spiral casing, in general, SB 46B (boiler plate No. 3 Class B) or SS 41P (normal steel plate) is used; however SM 50B (rolled steel for welded construction, No. 2 Class B) was specially considered, comparision of the latter with SB 46B discussed.

That is, as to the weldability of each, SB material has so far been developed for riveted construction: in order to increase the strength, its carbon content is increased; SM material increases the other alloy elements such as Mn, Si etc. keeping the original low-carbon content. Thus the hardening factcr of the latter is less than the former. A carbon equivalent is Cequ = 0.45 in the case of SM 50B and Cequ = 0.44 in the case of SB 46B, so actually there is very little difference between weldabilities as far as carbon content is concerned. As for notch brittleness, shock value is standardized for SM material, which is much better than SB material, yet tensile stress and yield point for SM material are higher. Because SM material was found to be most advantageous, SM 50B was selected for use in this power station. The maximum thickness of spiral casing is 36 mm. When a high tensile steel is used for the spiral casing, steel of matching strength must be selected for the divided flanges. For the present casing, cast steel SC49 of low carbon content was specially specified for use.

Fig. 10 shows the spiral casing being welded.

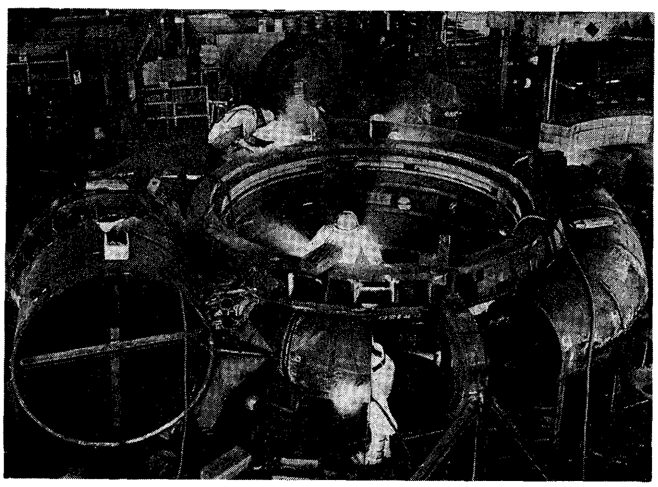


Fig. 10 **Turbine spiral casing**

Thin bolts of high tensile steel were used for tightening the flanges.

The hydraulic pressure test was carried out for the spiral casing combined with the inlet valve casing and with the terminal end flange of penstock as shown in *Fig. 11* with no occurrance of water leakage of deformation whatsoever.

A self-lubricating system by means of an oil immersed viscosity pump was used for the main bearing. In the conventional self-lubricating system, the sliding part of turbine shaft is perforated to circulate the oil by pumping action controlled by difference of peripheral speeds; however, in the present system, 6 oil slots formed as shown in *Fig. 12* were made on the lower inside periphery of bearing to circulate the oil by utilizing viscosity of oil. Please refer to the figure: *A* is suction and *B* is outlet; the oil is delivered to *B* through gap *C* and is raised to the slots on bearing inner suface from *B* for lubrication. Further suction pipes are provided on this suction inlet so as to raise the oil in oil tank from the bottom to circulate effectively.

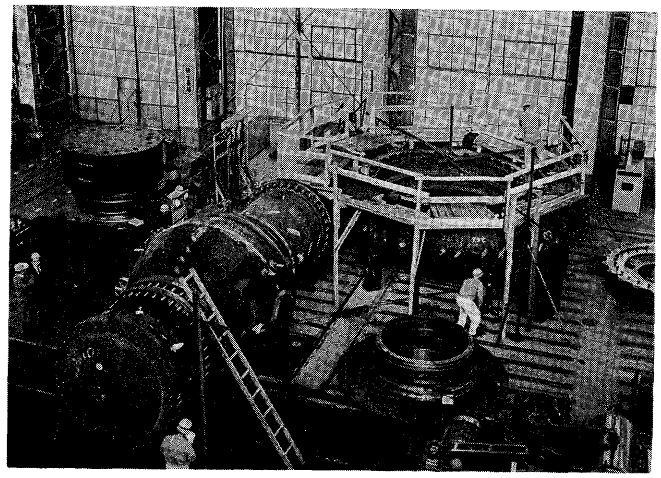


Fig. 11 **Turbine spiral casing and inlet valve under water pressure test**

The cooling system has adopted the use of a separately installed cooler inside the barrel and a water jucket. The oil, as shown in *Fig. 12* is circulated by the bearing viscosity pump to cool the bearing sufficiently. For this bearing device, a combined test for the actual product was carried out by changing oil temperature and revolution at our factory. As a result of the test we have confirmed that the oil discharge was much greater than in the conventional

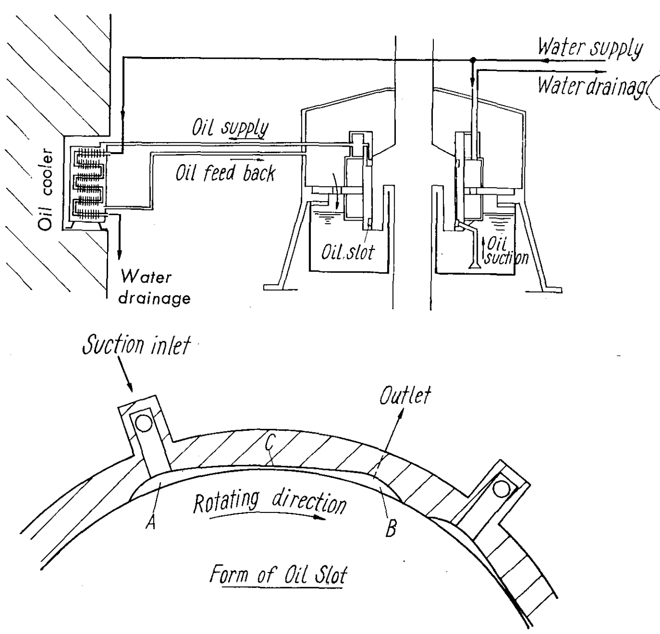


Fig. 12 **Main bearing lubricating system**

system, so it was more than enough to justify its use in spite of decreased oil discharge and head due to lowering of viscosity. There was no question of resistance loss during oil circulation in the cooler. This self-circulating system does not neccessitate an exclusive pump, so we are sure it will enjoy popularity in the future. The main bearing oil tank adopted a new type of construction as shown in the sectional view of *Fig. 9*.

An oil immersed oil tank of conventional type is divided in two, each coupled by flanges, so as to be able to disassemble the full tank. Oil in the oil tank, especially oil inside the skirt of turbine bearing during operation makes a rotating motion by rotation of turbine shaft; the coupling flange must be constructed inside of oil tank, therefore oil rotation is liable to be obstructed, resulting in overflow of the rising oil. This flange is further covered by a cylinder and walls made double to make smooth circulation of oil, free from any resistance.

The oil tank is separated into two parts, internal and external, and only the latter is divided in two sections (for disassembly); The internal oil tank (of unit construction with a cylinder welded when machining the turbine shaft) is machined concentrically with the turbine shaft and does not provide a flange, so it is made in single wall. Therefore the internal oil tank, being a part of the turbine shaft, cannot be disassembled, but easily inspected and assembled.

The important features of this single wall type oil tank are extremely simple construction, decreased peripheral speed (minimum bearing diameter), and the fact that the bearing can be lowered to approach the runner because of space not needed for disassembling the oil tank, and so forth. Various kinds of tests were devised for this oil tank during bearing tests. While observing influence due to eccentricity of oil tank to turbine shaft, we found that no influence due to eccentricity was evident; rather there was a tendency toward lowered oil level in the oil tank by oil rotation. There was no evidence at all of overflow of oil. The runner is made of 13% chrome cast steel, equipped with a 2-stage labyrinth, upper and lower sides, to balance hydraulic pressure and protect against water leakage.

Fig. 8 shows the assembly of water turbine at our work shop.

2. Inlet Valve

Because of high head power station, our special rotary valve was adopted; main parts such as valve case, valve plug etc. are made of cast steel. The diameter of main valve is 1600 mm; the bypass valve is a needle valve with a inlet diameter of 150 mm. This type of rotary valve has so far been supplied to several power stations and its accurate function has been proved, above all, in its closing action: watertightness is insured by the sealing plate installed in the valve.

The servomotor is composed of two units, stand type, installed on each side of the valve, made to close the valve during water flow at turbine full load.

3. Speed Governor and Oil Pressure Supply System

A cabinet type electric speed governor was adopted: all operations can be controlled from the switch board. Two units of guide vane servomotors are installed under the floor of turbine room. Our electric governors are in use in many power plants, earning an excellent reputation. They have already been introduced in Fuji Electric Journal, so please refer to the same for details.

The oil pressure supply system is a unit system; for both oridinary and stand-by use a motor-operated system was adopted. A vertical shaft screw pump, having a discharge pressure 25 kg/cm^2, capacity 300 l/min, revolution 1460 rpm was used. Ordinary oil pressure is adjusted to an upper limit 25 kg/cm^2 and a lower limit 23 kg/cm^2. *A* oil pressure tank with a capacity of 4740 l is installed beside the cabinet in the turbine room. The oil lever regulator of tank, because of high pressures to 25 kg/cm^2 adopted an automatic air compressor feeding system, first used by the Oyodogawa No. 1 Power Station. Air is directly supplied from air tank by an exclusive air compressor for the purpose of complete separation of oil and air, so that variation of oil character due to adiabatic compression of air bubbles produced in the oil is prevented. Further air supply and suction for this oil lever regulator is carried out only when unloading of oil pressure pump; each detection and control for operation settlement of oil level are done mechanically by means of float valve. Control valves etc. of oil lever regulator for air compressor, pressure oil pump, etc. are well arranged together on the oil pump tank and lubricating oil tank to minimize the space needed for installation.

4. Cooling Water Supply System

Each feed water pump, ordinary and standby, is used for each unit of water turbine, water in the draft tube used for the supply system. A vertical type automatic rotary strainer is installed at the pump outlet. As the cooling water is pumped up from the draft tube, it is liable to contain air bubbles which may decrease the cooling effect. So in order to completely eradicate the bubbles, a water tank was installed.

Notwithstanding difficulties of underground installation of water tank in such an underground power station as this, it was built successfully by utilizing the inclined shaft and arched horizontal shaft for transportation. The water supply valve (a motor operated type supplied by our Company) was mountod in the inclined shaft.

V. CONCLUSION

We have introduced the water turbine of Shimotaki Power Station in the above paragraphs. All turbines and accessories have already been delivered to the site and are under erection. The power station is expected to operate beginning in October, 1963. We wish to express our gratitude to the engineers of Tokyo Electric Power Co., Inc. who were of such great service in the designing and manufacture of this record-making product.