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Development of Niigata-NGT3B gas turbine for large standby generator set

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Abstract: Niigata Power Systems Co., has developed new gas turbine NGT3B which installed in a large standby generator set. This gas turbine engine meets a large capacity of important facilities in japa metropolitan areas. It is installed in CNT-3000EA generator set which generates 3,000kVA. Furthermore, it is scaled up to 6,000kVA by using twin NGT3B gas turbine. Although the generator set is large, it can be quickly started within 40 seconds defined by the fire defense law in Japan. An additional specification of rapid restarting within 40 seconds after engine stop increases reliability for a standby generator set. The other features are lightness, a digital control, a remote monitoring system and a low leakage lubricating system. The gas turbine engine is composed of a single shaft, two-stage centrifugal compressor, three-stage axial turbine, a single can combustor, and a dual fuel injector. One characteristic is turning-less for rotor cooling after the engine stops. Characteristic positions of rotor bearings realize it. The rated output power is increased from 2207kW to 2648kW by the improvement of NGT3A base model. A thermal efficiency achieves 24.7%. On the other hands, the maximum power is 2800kW, so some margin is given to the rated output power. Durability against the heat cycle by the fast start is tested by repeated engine starts and stops. And rapid restarting tests within 40 seconds are done on the assumption that power grids are returned during the engine stops. Long no load continuous running tests improve reliabilities of early standby to blackout. Over load tests confirm the durability of hot parts. There is no problem for durability of the engine. Any remarkable decrease in performance can be detected in the durability tests. This paper describes the design features of major engine component and a generator set for NGT3B. An engine performance and durability tests results are also shown.

INTRODUCTION

Based on self developed gas turbine engine, Niigata Power Systems Co., offers a line of standby generator sets with outputs ranging from 250 kVA to 5,000 kVA. In recent years, the capacity requirements of major facilities (intelligent building, data center, waterworks facilities, and drainage facilities) in Japan's metropolitan areas have increased. Due to the critical roles played by such facilities, standby generator sets must be highly reliable and able to provide significant amounts of electric power in the event of a blackout. On the backgrounds, Niigata Power Systems Co., Ltd. has the newly developed NGT3B gas turbine. It is installed in CNT-3000EA generator set which generates 3,000kVA. Furthermore, the output power is increased to 6,000kVA using the twin NGT3B, it is called CNT-6000EN. Table 1 compares conventional gas turbine against the latest lineup of Niigata gas turbine standby generator sets in the NGT series. Previously, capacities of 3,000kVA required NGT2A-T of twin gas turbines. Now, NGT3B of a single gas turbine can cover the 3,000kVA class. This 3,000kVA by single gas turbine is a first in standby generator sets. NGT3B was released in spring 2009 after many kind of evaluation test.

Table 1 — List of Niigata gas turbine

Electric output KVA	Gas turbine		
	Rated power kW	Conventional	Latest
1,250	1,103	NGT2-S	NGT2-S
1,500	1,324	NGT2A-S	NGT2A-S
2,000	1,765	NGT2B-S	NGT2B-S
2,500	2,207	NGT3A-S	NGT3A-S
3,000	2,648	NGT2A-T	NGT3B-S
3,500	3,089	NGT2B-T	NGT2B-T
4,000	3,530		
5,000	4,413	NGT3A-T	NGT3A-T
6,000	5,296		NGT3B-T

-S: single-type, -T: twin-type.

OVERVIEW

Table 2 gives the basic specifications of the CNT-3000EA and CNT-6000EN generator sets incorporating the NGT3B gas turbine. The engine is mainly composed of a two-stage centrifugal compressor, a single can combustor and a three-stage axial turbine.

Figure 1 shows a standard performance diagram of CNT-6000EN.

Figure 2 shows a CNT-3000EA generator set with a single NGT3B-S gas turbine. Figure 3 shows a CNT-6000EN generator set with twin NGT3B-T gas turbines. In both photographs, the NGT3B gas turbine installed on the engine bed seen from the exhaust side is shown.

Table 2— Basic specification

Generator set	CNT-3000EA	CNT-6000EN
Electric output	3,000kVA (2,400kW)	6,000kVA (4,800kW)
Frequency	50 / 60 Hz	
Starting time	Within 40 sec.	
Fuel types	Kerosene , Diesel oil , High grade heavy fuel oil , Gaseous fuel	
Gas turbine	**NGT3B-S**	**NGT3B-T**
Maximum Power	2,800kW	5,600kW
Rated power	2,648kW	5,296kW
Rotor speed	17,600 min-1	17,600 min-1
Compressor type	Two-stage centrifugal	
Combustor type	Single can type	
Turbine type	Three-stage axial	

Figure 2— NGT3B-S for CNT-3000EA

Conditions :
Atmospheric pressure 1013hPa
Intake pressure loss 0kPa
Exhaust pressure loss 0kPa
Lower calorific value 42.7MJ/kg(Diesel oil)

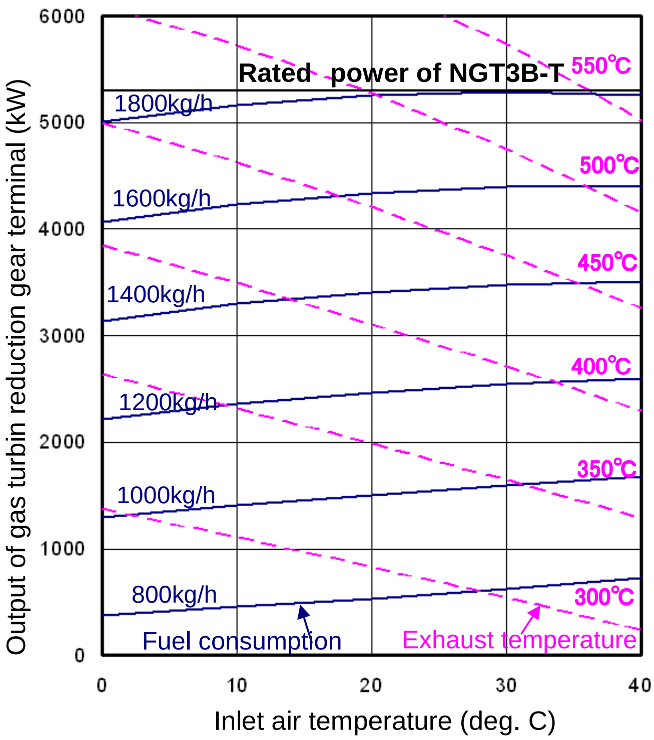


Figure 1— Nominal performance curves of NGT3B-T Gas turbine

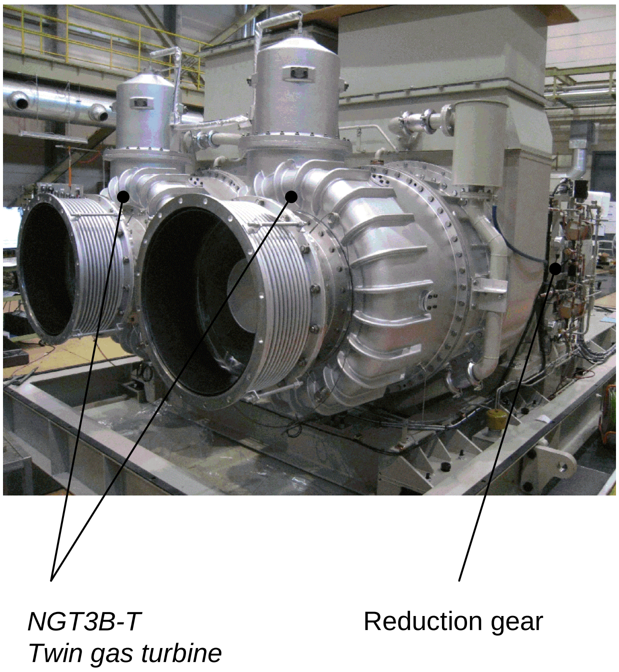


Figure 3— NGT3B-T for CNT-6000EN

NGT3B features topics are shown below.

1. NGT3B gas turbine features

[1] Simple construction and high reliability

The engine components are quite simple with shingle shaft, two-stage centrifugal compressor, three-stage axial turbine and a single can combustor. The combinations of these major components are conventional and proven for a long time. Figure 4 shows 3D model of the NGT3B engine.

[2] High-power and high-efficiency

Maximum output power is 2,800kW. In actuality, the output power is derated to 2,648kW with thermal efficiency of 24.7%. The derated use sets a safety margin for the durability of hot parts.

[3] Powered by dual fuel

Both liquid and gaseous fuels are selected to meet several demands in customers sites. Dual fuel-sources is suitable for disasters in metropolitan areas.

[4] Turning less

A unique layout of rotor bearings makes it needless to turn the engine rotor for cooling. It simplifies the sequence programs after the engine stops, so operation becomes easier.

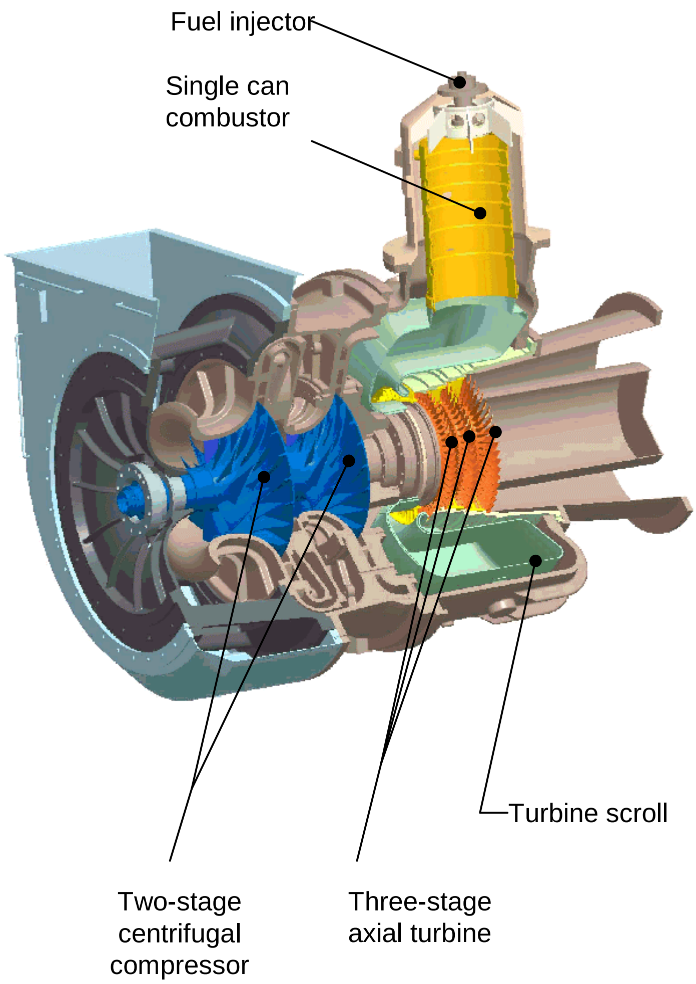


Figure 4 — Cutaway view of NGT3B

2. Standby Generator set features

[1] Starting time within 40 seconds

The generator supplies electricity within 40 seconds after blackout occurs. The specification meets the fire defense law in Japan.

[2] Rapid restarting time within 40 seconds

Restarting within 40 seconds after engine stops is available by detailed digital engine controls. The system makes ready to blackout during engine stops.

[3] Digital controller

The enclosure set includes a full digital controller which realizes detailed fuel controls to meet several engine operate conditions.

[4] Remote monitoring system

A remote monitoring system via internet supports detailed and timely supports.

[5] Light weight and compact

Other features include a light weight and compact size for easy installations.

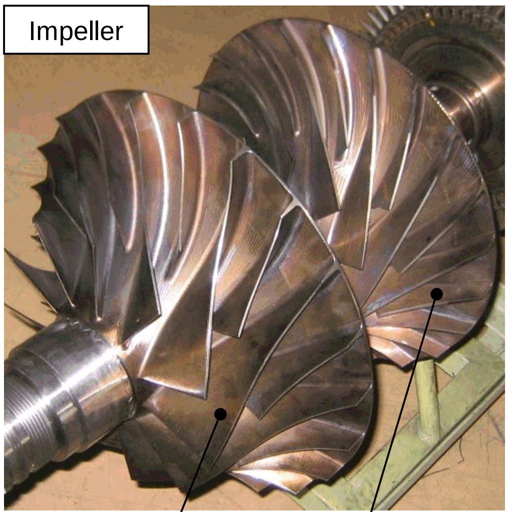
[6] Low-leakage lubricating system

An unique lubricating oil system modifies oil leakage problems.

The NGT3B achieves both cost efficiency and high reliability based on the NGT3A of 2,207 kW. The rated output power has increased from 2,207kW to 2,648kW by the improvement NGT3A base model. To increase base engine NGT3A output by 20%, hot parts of the NGT3B are scaled up from those of the NGT2B which has good performances to high pressure ratios and high temperatures. Detailed design features are described as follows. The test results for engine performance and durability are also shown.

COMPRESSOR

Figure 5 shows compressors and a diffuser for the NGT3B. The two-stage centrifugal compressor are applied as the same ones in the NGT3A. The compressors are made of a forged 17-4PH, cut with a 5-axis machining center. At the rated output, a pressure ratio of 8.1 and an air flow rate of 13.0 kg/s are performed with efficiency of 80%. Diffusers set up outside of the compressors are matched up to achieve high turbine inlet gas temperatures.



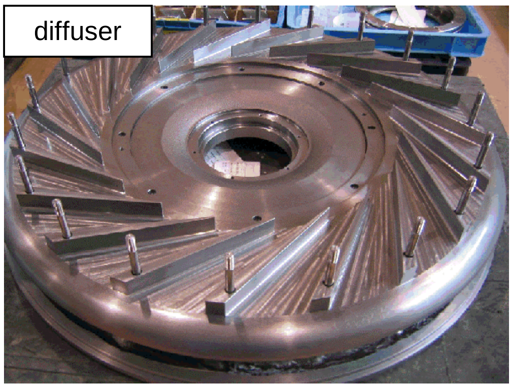


Figure 5 — Compressor

COMBUSTOR

Figure 6 shows the NGT3B combustor. A single can combustor is applied. A thermal barrier coating is given on the inner wall for long life. The assembly of the case and liner can be set in and off simultaneously to the turbine casing, so maintenances can be very easy.

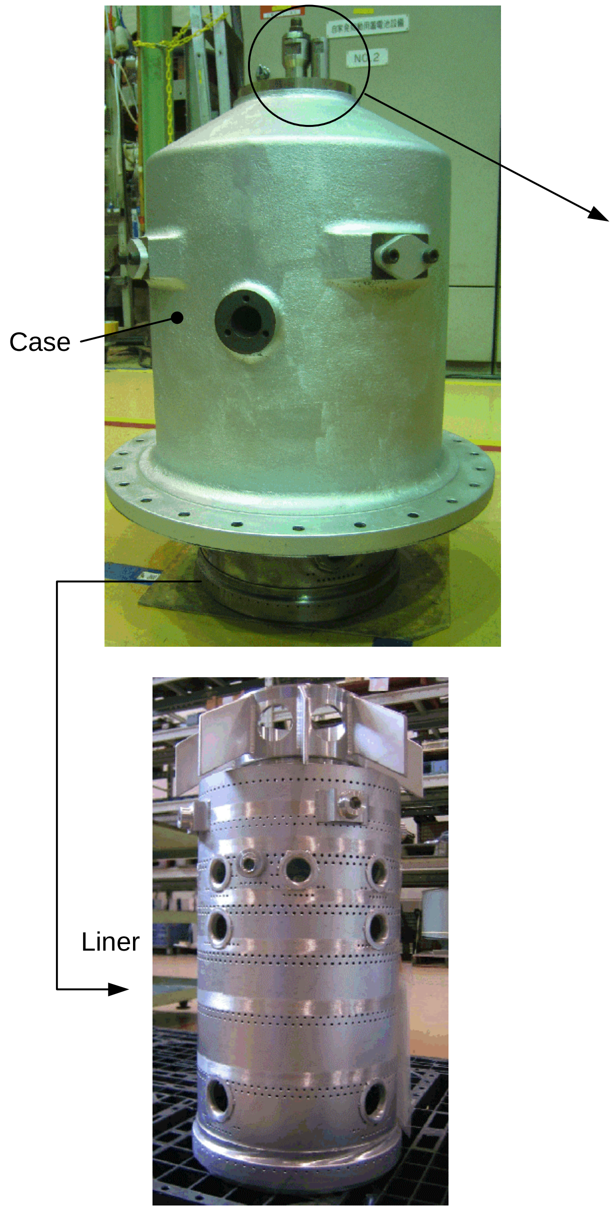


Figure 6 — Combustor

FUEL INJECTOR

Figure 7 shows a fuel injector. It has coaxially-mounted a pressure atomizer and air blast atomizer. The pressure atomizer having good atomization characteristics offers excellent ignition performance. The air blast atomizer produces clean exhaust emissions. A gas nozzle is attached to the upper part of the fuel injector. This configuration allows easy switching of single and dual fuel operations.

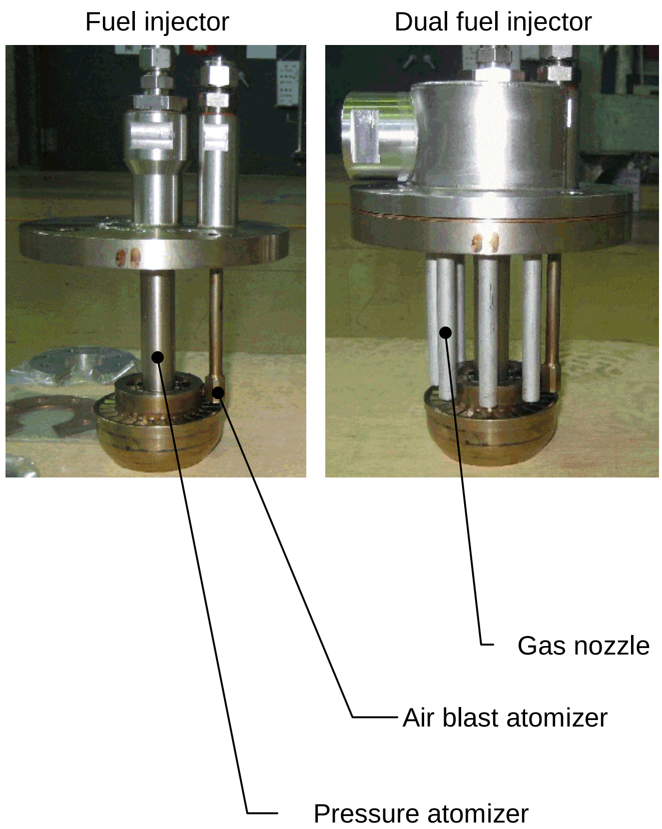


Figure 7 — Fuel Injector

TURBINE SCROLL

Figure 8 shows an NGT3B turbine scroll. The turbine scroll is made of a nickel-based alloy. The parts are made by using a spinning process and assembled by welding. The structure of the turbine scroll is a simple configuration that results from scaling up the turbine scroll of the NGT2B gas turbine, increasing the thickness of the sheet. The surface temperature tends to rise with higher gas turbine output power. It can prevent reduction of efficiency without increasing cooling air flow rate that the air hole positions are modified using CFD analysis.

Figure 9 shows temperature distributions on the turbine scroll surface obtained from CFD. Exhaust gas from the combustor go into the turbine scroll by a single inlet tube like figure 8. Therefore, the turbine scroll temperature tends to be non-uniform distributions. To enhance uniform temperatures, cooling method on the front side was optimized by changing the positions and size. On the rear side, thermal stress was reduced by thickening sheet metal without cooling. In the part without cooling, there was temperature distribution non-uniform as shown in Figure 9 either. The measurement result of the hot section that was selected from the CFD analysis was below a permissible maximum temperature.

Figure 8 — Turbine scroll for NGT3B

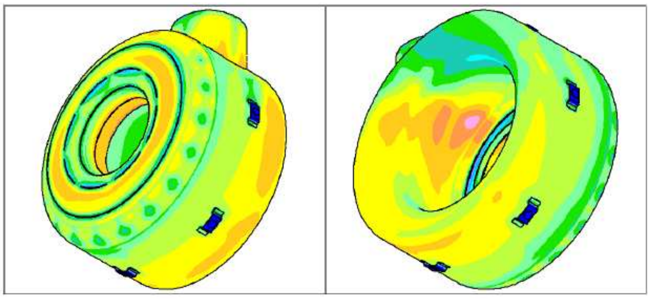
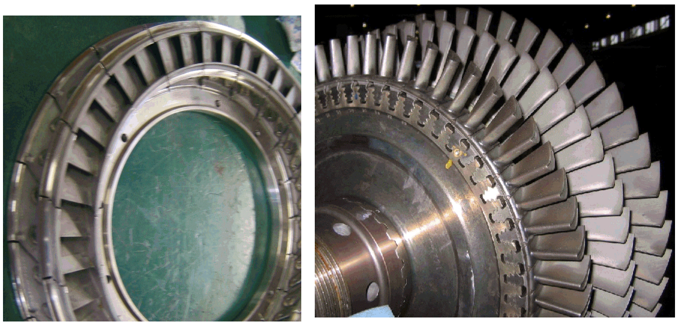


Figure 9 — Temperature distribution of turbine scroll by CFD analysis

TURBINE

Figure 10 shows turbine assemblies. It is a three-stage axial turbine. Matching the first-stage nozzle and blade is modified from NGT3A, and results in higher turbine inlet temperatures and pressure ratios. The first-stage nozzle is scaled up from one used in the NGT2B with precision-cast from a cobalt-base alloy. The first-stage blade is scaled up from the one used as a cooling blade in the NGT2B, with precision-cast from nickel base alloy. The second and third stages are common with those of NGT3A, so interchangeability is maintained.



First stage turbine nozzle   Turbine rotor ass'y

Figure 10 — Turbine assembly

SHAFTING

Figure 11 shows a rotor assembly. The assembly combines the compressor and turbine assemblies. The compressor is assembled by tightening a two-stage compressor and a rotor-shaft with a center stud. The turbine is assembled by tightening a three-stage turbine rotor and the rotor shaft with a turbine-bolt. The coupling face of the compressor, the turbine, and the rotor shaft are linked by curvic couplings for reliable and low-vibration operations. The rotor is supported by two bearings positioned at both ends of the rotor shaft of the compressor assembly. Ball bearing is positioned at the compressor side and roller bearing is set at the turbine side to support the entire assembly. Reducing the length of the rotor shaft between those bearings minimizes shaft deflections caused by heat transfers when the engine stops. This results in unnecessary turning for rotor cooling and simplifies operations.

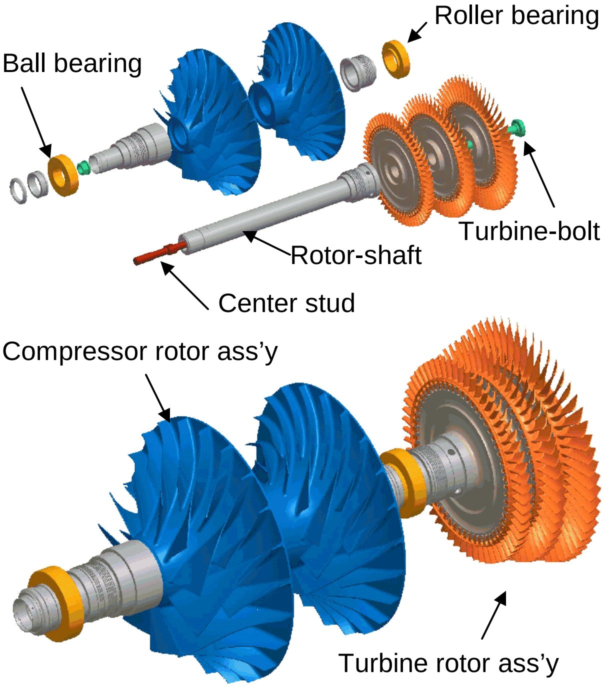


Figure 11 — Rotor assembly

REDUCTION GEAR

Figure 12 shows the reduction gears used in the CNT-3000EA and CNT-6000EN. The reduction gears are newly designed because of increasing the power of the base engine by 20%. The new reduction gears make it possible to retain the same size of the base engine while simplifying construction and reducing the number of parts. The reduction gears used in the CNT-3000EA are one stage planetary types. The reduction gears used in the CNT-6000EN are one stage planetary and spar gears. A starting drive unit with a one-way clutch, lubricant pump, and fuel pump were positioned on the generator side of the reduction gear.

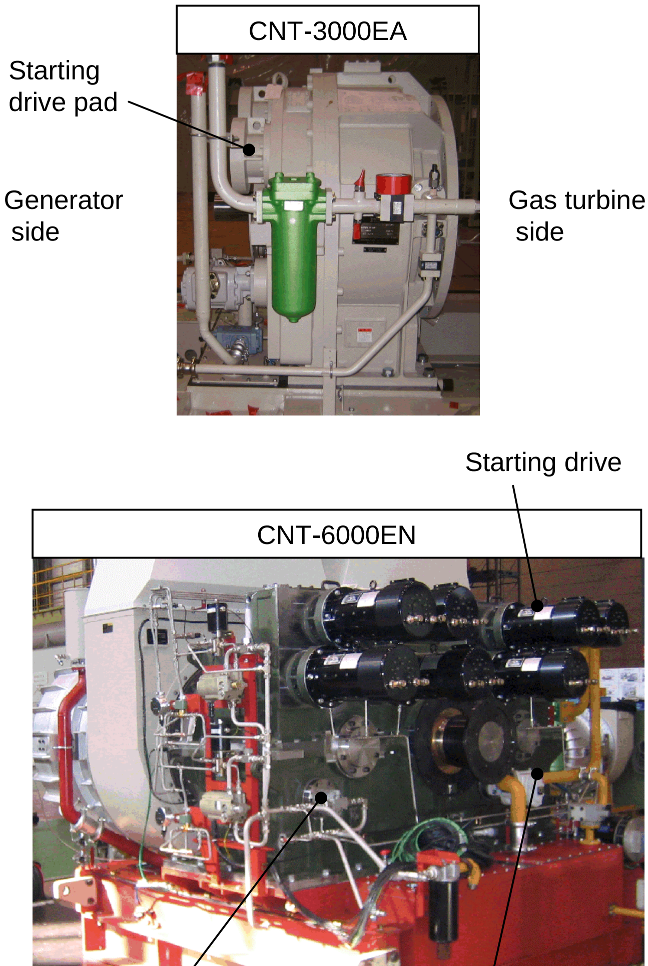


Figure 12 — Reduction gearbox

A UNIQUE LUBRICATING OIL SYSTEM

Figure 13 shows a shaft seal schematic. The shaft seal applies a labyrinth seal retained by compressor discharged pressure. The air pressure discharged from the compressor tends to drop under the low rotational speed (e.g., when the engine is stopped). It weakens the shaft seal with increasing the possibility of lubricating oil leaks that compressor discharged pressure becomes low under the engine stops. An oil control system was modified to prevent these oil leaks.

Figures 14 and 15 compare the latest lubrication system used in the NGT3B to the conventional system. The lubrication system is divided by the check valve „B“ into a main system and a priming system, as figure 15. The pumped priming oil is supplied only to plain bearings included in the planet gear of reduction gear because of having large friction . In contrast, no priming oil is supplied from the electric pump to the roller bearing of gas turbine, where friction is low. This system prevents oil leaks from the shaft seal via oil priming at low rates of revolution. It also eliminates any need for detailed control of the motor pump for oil priming.

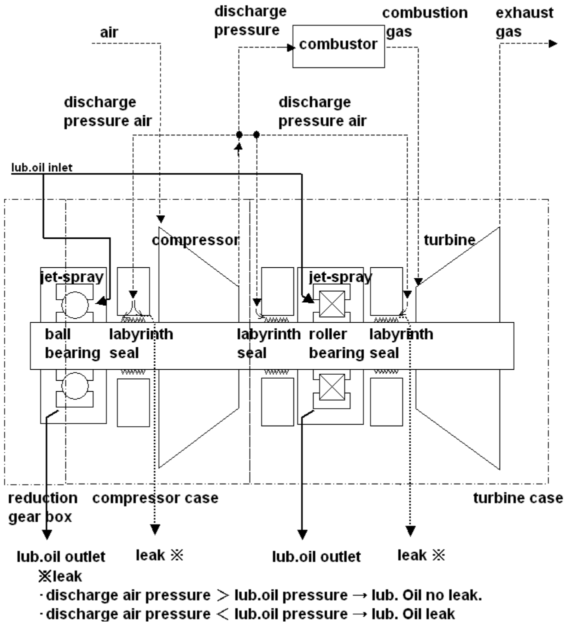


Figure 13 — Bearing seal

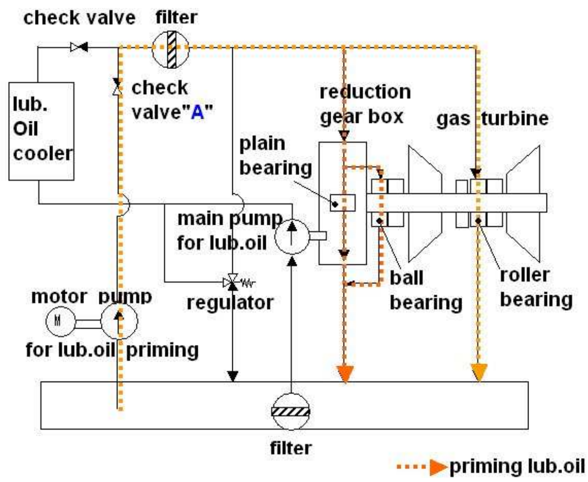


Figure 14 — Conventional lubricating oil system

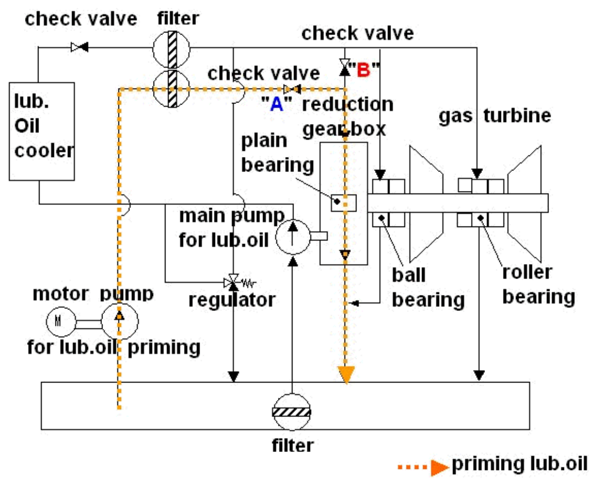


Figure 15 — Latest lubrication system

ENCLOSURE

Standby generator sets may need to be installed in a wide range of locations ranging from ground level or underground to a building roof. This requires a low weight. To meet this need, NIIGATA took steps to make the enclosure weight saving.

Figure 16 shows a cross sectional view of a CNT-3000EA generator set. The air intake duct and suction silencer structure are modified based on those of the 2,500 kVA generator set to reduce weight while meeting typical noise specifications of 85 dB. Construction was simplified by modifying the structure of the engine bed and installing a vibration isolator at the barycentric position of the generator and the gas turbine. These efforts resulted in weight savings of 10% compared to a conventional CNT-3000E generator set using NGT2A-T gas turbine. Another result is that the CNT-6000EN is not significantly heavier than the base CNT-5000EN. The result is a 14% decrease in weight-to-power ratio compared to conventional systems.

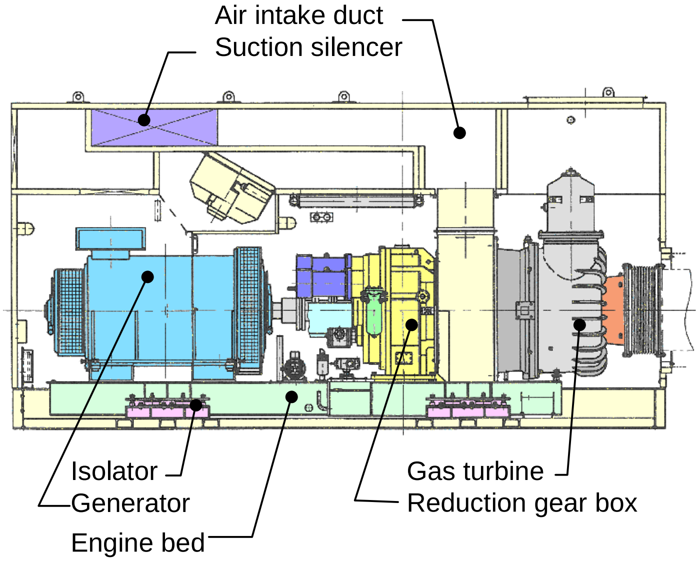


Figure 16 — Generator set of newly model CNT-3000EA

ENGINE CONTROLLER

Figure 17 shows a engine controller of CNT-3000EA generator set. The engine controller is built into the enclosure. This configuration minimizes the effects of noise compared to conventional external wirings and improves control reliability. The system uses a remote input-output system that allows signals to the engine controller, generator panel and DC power supply panel via the communication cable. This approach eliminates the need for other conventional external wiring and further simplifies installation. A flexible, all-digital, rotational speed control system ensures excellent starting performance and prompt response to changes in load. The engine controller is built into the enclosure.

Figure 17 — Engine controller of CNT-3000EA

REMOTE MONITORING SYSTEM

Figure 18 shows the outline of the remote monitoring system. In the standby generator set, the remote monitoring system becomes important because of a high reliability. The NIIGATA remote monitoring system (It is called NESTY) only sets up the terminal in the engine controller. The engine start-up data and state data in the case of the unusual are transmitted to the telemonitoring center through the telephone line automatically and it is accumulated in the database. NESTY uses this data base and has the following features. The data of the telemonitoring center can be monitored with each customer support branch and mobile PC. The engine start-up data can be observed in the tendency, and the state of the engine. It becomes easy to presume the failure cause by the failure data analysis before it investigates in the site, and it is possible to increase a reliability of standby generator set.

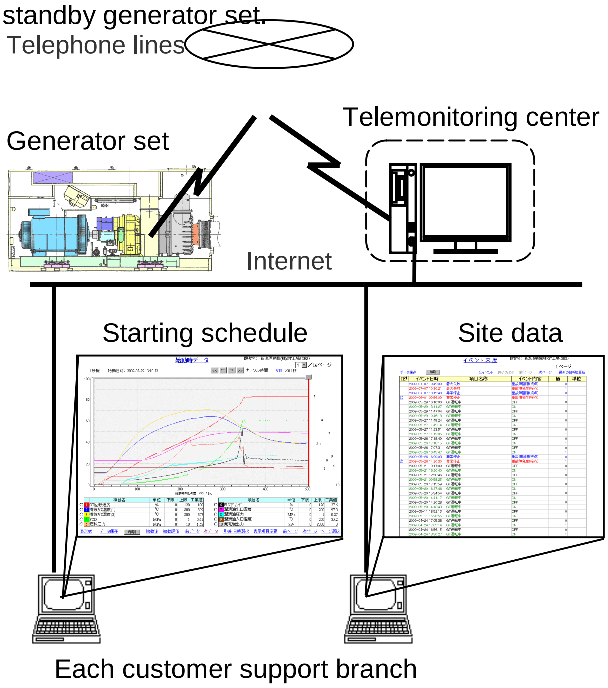


Figure 18 — Remote monitoring system

DEVELOPMENT TESTING

Startup, restart and durability tests confirm that the standby generator set provides the necessary performances and reliabilities.

TEST RESULTS FOR STARTUP AND RESTART PERFORMANCE

Figure 19 is a standard start trend graph when the engine starts. Both of the CNT-3000EA and CNT-6000EN start up in less than 40 seconds after a start command is issued. The start time of 40 seconds meets the requirements of the fire defense law in Japan. Hot starts within 40 seconds are possible without turning the engine after cooling by full digital engine controls.

Figure 20 shows a rapid restart trend graph. Even if the start command is reissued after during the engine stops, the system can still start up again in 40 seconds or less by detailed fuel control using the digital engine control. Niigata developed and released this technology into actual products in 1999, and it has led to a lot of delivery results.

DURABILITY TESTING

Figure 21 is a photograph showing the exterior of the generator set used in these evaluations.

TABLE 3 shows durability testing result.

NGT3B installed in CNT-3000EA is tested more than 1,200 cycle engine starts to confirm the durability of the parts exposed under the high mechanical and thermal stresses.

Figure 22 shows examples of trends for a start cycle test. Moreover, to confirm the durability of hot parts, the 10% overload durability test was continued in 100 hours in addition to 300hours operations under rated load. Total testing time resulted in at least 500 total operating hours. The standby generator sets are also subjected to the term in which it is operated under no load for extended periods in thunderstorms. To confirm the reliability of the transmission torque under no-load conditions, 50 hours no-load operations are conducted. The restart tests are repeated more than 50 times to confirm the reliability of the starting motor drive unit and the restart system. The performance of the NGT3B remains the same by checking engine performances before and after the durability tests.

Figure 23 shows some parts after durability testing. The durability tests confirmed the reliability of the all parts.

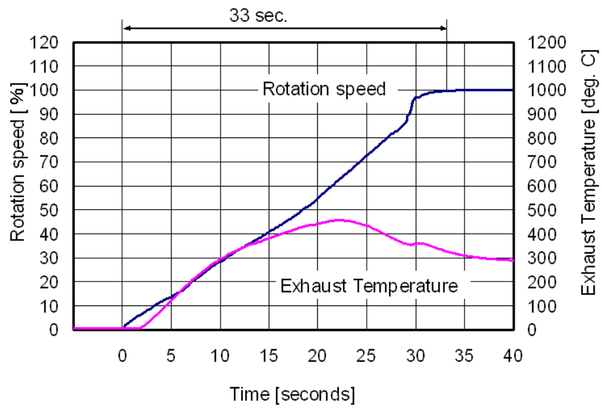


Figure 19 — Starting Schedule

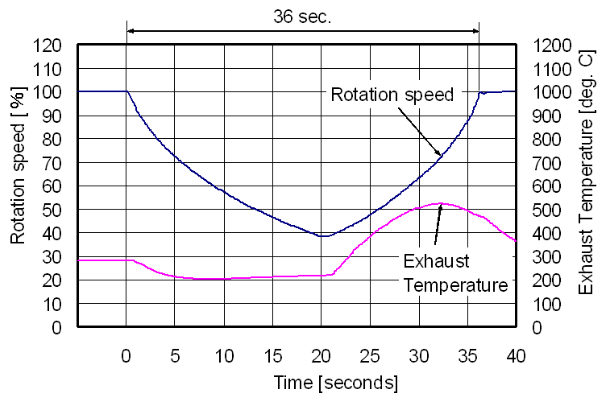


Figure 20 — Restarting Schedule

Table 3 — Durability testing result

Item	Result
Start up Cycle test	Over 1,200 cycle
Rapid restart cycle test	Over 50 cycle
Total running time	Over 500 hours
Continuous running test under 10% over load	Over 100 hours
Load test	Over 300 hours
Continuous running test under No load	Over 50 hours
Others	about 50 hours

Figure 21 — CNT-3000EA generator set test facility

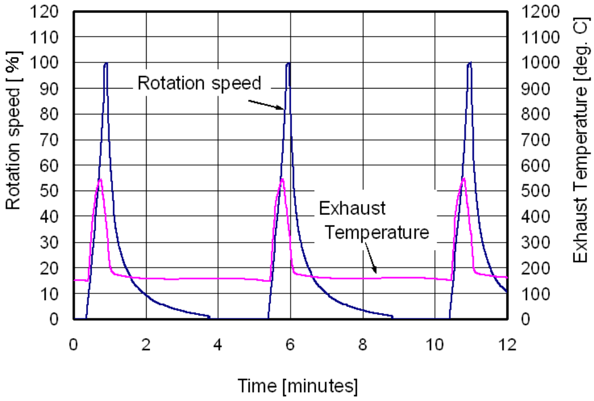
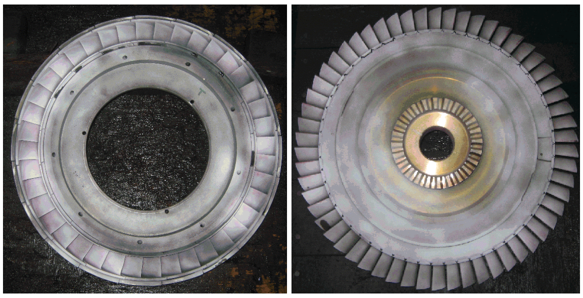


Figure 22 — start cyclic test trend.



First stage turbine nozzle Turbine rotor ass'y

Combustor Turbine scroll

Figure 23 — Main parts after the durability tests

CONCLUSIONS

The NGT3B gas turbine was developed for use in large standby generator sets that serve as emergency power source systems in metropolitan areas, where demand continues to rise for ever-higher capacity.

Incorporating proven technologies and long experience, the completion of the new NGT3B gas turbine adds the CNT-3000EA and CNT-6000EN to the product lineup of standby generator sets.

NIIGATA expects growing numbers of customers to adopt the large standby generator sets.

ACKNOWLEDGEMENTS

We are deeply indebted to the numerous colleagues for various important contributions during the developments.

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