

# Development Strategy for Evaluating Gas Turbine Driven High-speed Alternator



Poonam Kumari, V. Prabakar, and A. N. Vishwanatha Rao

**Abstract** In this paper, strategy for development of high-speed rig for performance evaluation of gas turbine driven alternator is discussed. In aeronautical systems, only high-speed alternator is the power generating unit, which is directly or through gear train coupled with variable speed gas turbine engine. Performance evaluation of this type of alternator needs to be conducted on bench to validate its rating. Development of high-speed (30,000–60,000 rpm) rig is really demanding to meet this performance evaluation requirement. Apprehension and challenges for development of high-speed rig, instrumentations, and its rig characterizations are presented in details.

**Keywords** Air turbine · Current transducer · Drive · Data acquisition · Gas turbine · High-speed motor · High-speed alternator · Power supply

## 1 Introduction

Gas turbine driven alternators are specially designed for high-speed applications and also considered for high-temperature environment. Basically, permanent magnet technology-based alternator is the best candidate for this condition, but homo-polar technology-based alternator also plays good role for such kind of application in less efficient way [1, 2]. Evaluation of these types of alternator is a great challenge because its characterization completely depends on rotor speed. Variable speed control of rotor can be achieved by means of integrated high-speed drive. Development of high-speed drive or rig totally depends on the prime mover capability to provide sufficient mechanical power to the coupled alternator without losing its control.

Air turbine and electric motor on this speed range can act as appropriate prime mover to meet the performance criteria. Many factors are influencing the development strategy for these kinds of prime movers. Air turbine-based prime mover demanding the capability of its turbine rotor to support the high-speed, whereas in case of electro-mechanical type prime mover, high-speed motor is used to produce enough

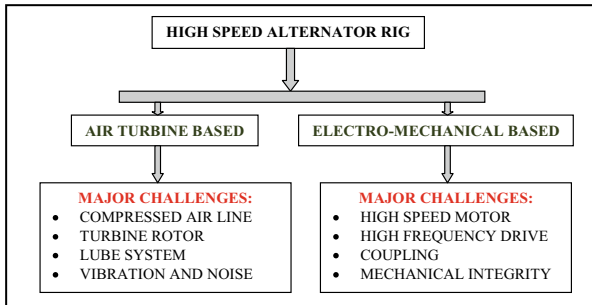
---

P. Kumari (✉) · V. Prabakar · A. N. Vishwanatha Rao  
GTRE, DRDO, Bangalore, India  
e-mail: [poonamkumari.gtre@gov.in](mailto:poonamkumari.gtre@gov.in)

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023  
G. Sivaramakrishna et al. (eds.), *Proceedings of the National Aerospace Propulsion Conference*, Lecture Notes in Mechanical Engineering,  
[https://doi.org/10.1007/978-981-19-2378-4\\_12](https://doi.org/10.1007/978-981-19-2378-4_12)

191

torque [3, 4]. Turbine rotor dynamics and motor inertia are important factors that affect the integrated sub-systems in terms of vibration, temperature, and its coupling. Challenges for both kinds of rig are depicted below:



This paper describes only air turbine-based high-speed alternator rig and also focuses on difficulties faced during rig development.

## 2 Air Turbine-Based Rig Setup

Rotation of shaft at high speed by means of any kind of prime mover introduces multifaceted technology. Air turbine-based rig was used to produce high speed to the shaft. This type of rig development associates many challenges with respect to development of air turbine rotor, compressed air supply and lube system, etc. System integration, mechanical integrity, and its operability are additional effort. To maintain and regulate the compressed airline pressure for long duration, it needs huge air reservoir with pressure regulator. This airline composed of a manual gate valve, a motorized gate valve for mass flow control, an orifice for mass flow measurement, a quick shut off butterfly valve to avoid over speeding of rotor in case of load interruptions, and a rubber bellow for vibration isolation. Precise operation and control of such a long air pressure line involve continuous monitoring and expertise.

After iterations, rig setup was attained to integration level to characterize the high-speed alternator. Major integration issue was related with turbine rotor assembly with alternator rotor. To achieve this, air turbine rotor was inserted into the hollow shaft of the alternator rotor and locked on the other side by using lock nut to transfer the torque. Another challenge was development of lubrication system to provide cooling and lubrication requirements of the alternator and its bearings, respectively. After continuous efforts and facing the multi-technological challenges, rig was developed. Rig layout and actual view of air turbine rig are shown in Figs. 1 and 2, respectively.

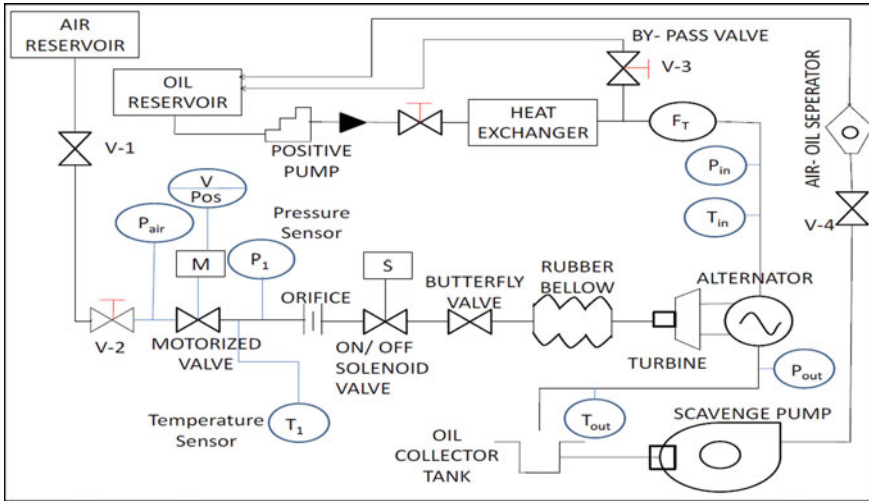


Fig. 1 Air turbine rig layout

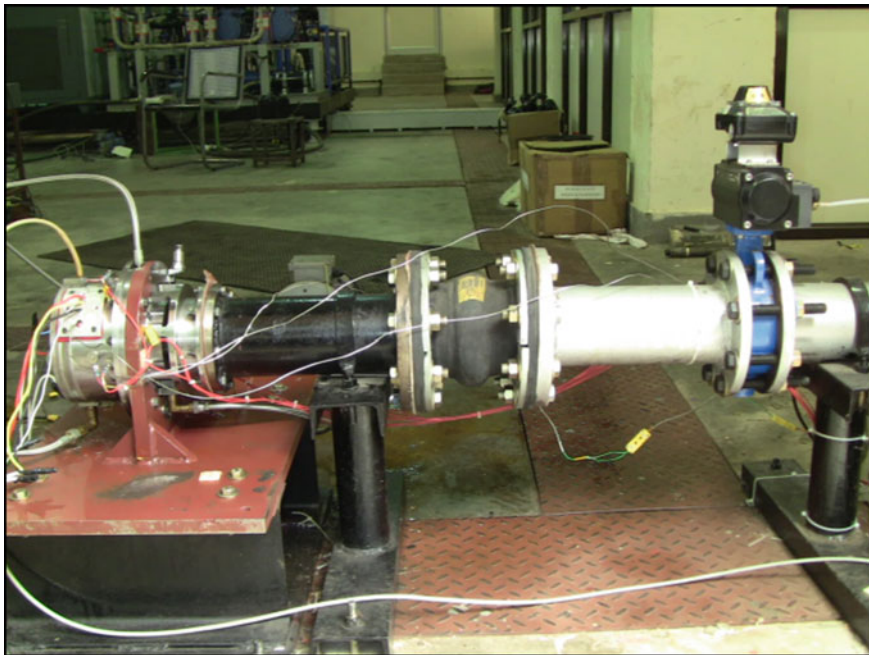
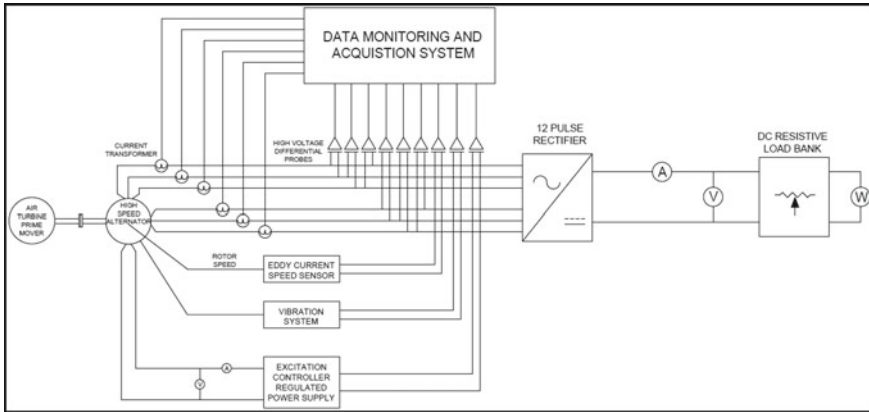


Fig. 2 Air turbine rig setup—actual view



**Fig. 3** Electrical instrumentation layout

### 3 Rig Instrumentations

Rig instrumentations for measurement of critical parameters are necessary before evaluation of integrated system. Hence, complete rig was instrumented with proper measuring device to capture the rig behavior. Significant mechanical and electrical parameters were measured and recorded in high-speed data acquisition system. Electrical instrumentation for system evaluation is shown in Fig. 3.

### 4 Measurements and Monitoring System

Measuring instruments and data acquisition system details are given below.

#### 4.1 For Mechanical Parameters

##### 4.1.1 Pressure

Turbine inlet air pressure and lubrication oil inlet pressure were measured by pressure transducer. All the pressure transducers/transmitters were calibrated by using pneumatic pressure and dead weight calibrator before use.

### **4.1.2 Temperature**

All temperatures were measured using K-type thermocouples in the range of 0–200 °C. Thermocouples were placed at various locations like lubrication oil inlet, lubrication oil outlet, alternator casing at front side, bearing housing, etc.

### **4.1.3 Vibration**

To monitor the vibration levels of the test rig and the integrated alternator, piezo-electric type accelerometers were mounted at critical locations on the test rig. The vibration data were acquired by using a multi-channel DSP base PROSIG system. Sensor with 31.6 mV/g sensitivity is used. The sensor outputs were connected to PROSIG system to monitored vibration level.

### **4.1.4 Speed**

Eddy current probe was used and mounted at rear side of the drive shaft. Output signal from the probe was conditioned through signal conditioner and given to the timer/counter unit, which was programmed to display the speed in rpm. Speed measurement is also possible by deriving the frequency from alternator output voltage.

### **4.1.5 Flow**

Measurement of lubrication oil inlet flow rate to the alternator is also important, and it was done by using a turbine flow meter.

## ***4.2 For Electrical Parameters***

### **4.2.1 Voltage Measurement**

Differential voltage probes with suitable attenuation ratio were used for voltage measurement purpose. All output voltages of the alternator were continuously monitored, and same signals are taken to the high-speed acquisition system for data logging and processing.

### 4.2.2 Load Current Measurement

High-frequency AC currents were measured by Hall effect current transducers with nominal output of 4 volts at full range. All transducers were located in proper place, and outputs were given high-speed data acquisition system for measurement and record purpose.

## 5 Data Acquisition System

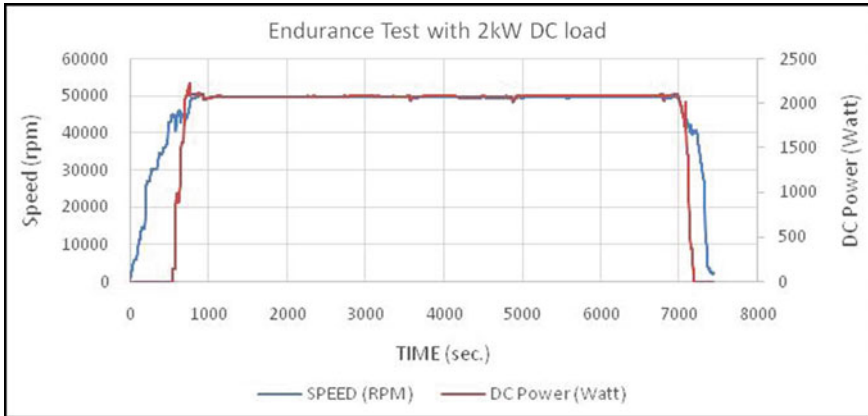
A high-speed data acquisition system (34970A) with a high bandwidth was designed by using a PXI-based embedded controller and data acquisition cards. All steady-state parameters were measured and given to the data acquisition card, which measures voltage, current, and frequency. All the process and instrumentation parameters were integrated to this system. All time domain signals, namely AC line voltages and AC line currents, were measured using two high-speed simultaneously sampling cards. This sampling card receives the raw data from high-speed instruments and after processing provides data to LabVIEW. Full alternator load test architecture is defined in LabVIEW in such a way that critical parameters like transients in voltage/current with respect to loading/unloading, output power, waveforms, etc., can be seen in real time and can also store data simultaneously for future analysis.

## 6 Rig Considerations

Rig was developed for performance evaluation of high-speed alternators. Rig characterization was carried out to ascertain its capabilities to achieve the desired requirements. Without alternator integration, preliminary checks like mechanical integrity, vibration, oil leakage, shaft rotation at various speeds were checked to assure rig operability. Shaft rotation at rated speed along with all controllable parameter was also conducted many times to avoid system failure during integral trial. Rig was subjected for no load test and load test separately. Details are given in succeeding paragraph.

### 6.1 No Load Test

Under no load test, turbine rotor system was first rotated at low speed and gradually increased to higher speed by means of increasing the air mass flow rate to the air turbine-alternator rotor system. This run was carried out without electrical load to understand the dynamics of the rig. Considering very high speed of alternator, the rotor was expected to have some critical speeds within its rated speed. Hence, the



**Fig. 4** Endurance test plot

vibration levels were monitored carefully to full speed, and resonant frequencies were identified to decide safe operational regimes during the run and to draw the test schedule. With this dynamic behavior of rotor system, safe test schedule is drawn to accelerate the alternator quickly while passing through resonant speed band. No load run up to full speed was carried out.

## 6.2 Load Test

After rig dynamic stability at high speed and confirming the comfortable region of vibration level, load test was carried out at 50,000 rpm. First, alternator was loaded in step up to 2 kW DC load by DC load bank, and parameters were measured. Subsequently, endurance test for continuous 2 h with 2 kW DC load was conducted to validate the alternator design parameters. All performance data were monitored and captured in data acquisition system for further analysis. Test results are plotted separately in Figs. 4 and 5.

## 7 Conclusion

Alternator was evaluated on air turbine-based rig with rated DC load. Common difficulties were observed with respect to critical speed, high vibration, bearing failure, and synchronizations with electrical equipment. Due to these great challenges, rig behavior was very unusual. Hence, all rig modules were subjected for many design iterations to meet development strategies. Multi-technology-based high-speed rig is successfully developed and evaluated with integrated alternator.

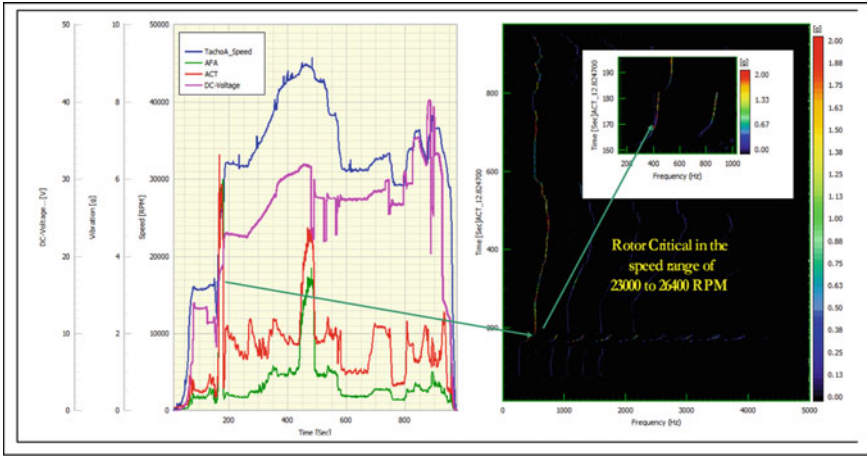


Fig. 5 Vibration plot

**Acknowledgements** The authors wish to thank, The Director, GTRE, Bangalore-93, for his constant encouragement and valuable guidance. Thanks to the entire GTRE team members for their valuable suggestions and support. Special thanks to propulsion division NAL, CSIR, Bangalore for extended cooperation and involvement in rig development and its operation, without which it could not have been possible.

## References

1. Tapani J (1988) High speed electrical machines. In: Proceedings of the conference on high speed technology, Lappeenranta, Finland, pp 175–185
2. Chudi P, Malmqvist A (1989) Development of a small gas turbine-driven PM high speed generator (HSG). Thesis, KTH, Sweden
3. Pyrhonen J (1988) Some aspects of high-speed rotor design in electrical machines. In: Proceedings of the conference on high speed technology, Lappeenranta, Finland, pp 231–246
4. Claire S Gas turbine, a hand book of air, land and sea applications