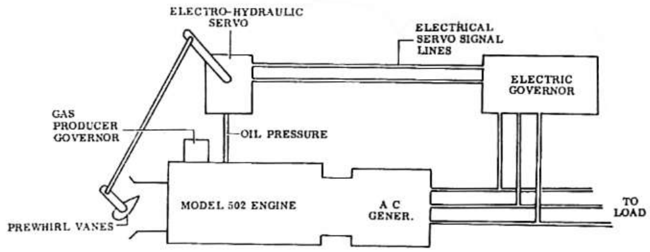

Fig. 17 Control system schematic

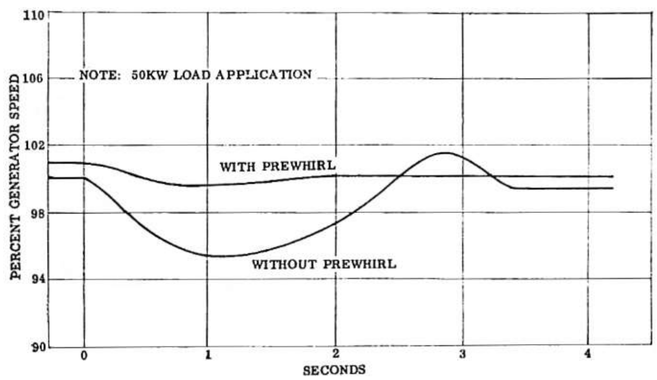

Fig. 18 Transient load response

The Control System and Its Response. Fig. 17 shows a schematic diagram of the control system. A gas producer governor controls the fuel flow to the engine. A speed and load sensing governor controls the prewhirl setting. The test set-up used to evaluate the prewhirl concept consisted of a Boeing Model 502 gas turbine driving a 75-kw, 60-cps generator. Various step loads were applied up to a maximum load of 150 kw. Generator speed and load were sensed by an electrical governor and corrective actions were made by a hydraulically actuated servo. Under steady load conditions generator speed controlled the position of the prewhirl vanes but when a sudden load was applied to the generator the load sensing elements in the governor would override the speed control and advance the vanes to a new position. When steady load was again established, control was returned to the speed sensing elements of the governor.

The fuel control valve was positioned by a governor which sensed gas producer speed and compressor air pressure. Under steady load conditions the fuel flow is regulated to maintain a constant compressor speed. However, since the fuel control valve is also positioned by compressor air pressure, fuel flow changes are also accomplished with load changes, i.e., prewhirl vane position without the need for compressor speed changes. Fig. 18 gives the transient load response with prewhirl as compared to conventional variable compressor speed control. It was found during these tests that power build-up occurs at essentially the same rate as the rate of prewhirl vane angle change.

Conclusion

A control system was developed which provides the two-shaft gas turbine with the capability for nearly instantaneous power response. This response is limited only by the rate at which the control elements can be actuated and the time it takes a change in air pressure at the compressor inlet to be felt by the power turbine. This response is in the order of 10 millisec in the case of the Boeing Model 502 engine and was accomplished while maintaining the performance advantages of the two-shaft engine.

DISCUSSION

H. Netsch[3]

The authors must be congratulated on their excellent solution of the complicated regulation problem, posed by two-shaft gas turbines. The amount of experiment and theory, which has been presented in a most concise manner, allows one to appreciate the excellent reasoning behind this development.

Gas turbines with a split turbine, where one stage drives the compressor, whereas the other provides the power, are preferred in automotive and stationary use. With the power turbine at zero rpm, a maximum of torque is obtained. Any variation in mass flow and fuel/air ratio will affect this value. The regulation is normally achieved by changing the fuel rate, thus also the speed of the compressor and its turbine, which indirectly affects the power unit. In the case of a turbine with a heavy rotor, this results in an undesirably sluggish response to load alterations. Any attempt to correct this leads to thermal problems and unduly high compressor speeds which narrow the zone between operating and compressor surge line.

In this new regulation development, the change in adiabatic head of the constant speed compressor is achieved by prerotating the entering air. Other methods influencing the pressure ratio of a compressor with constant speed are known. Throttling yields a drop in pressure; heavy throttling advantageously narrows down the surge zone, but gives a steep performance curve. As a result of the above-mentioned change, small mass variations cause large pressure variations and this leads to difficulties in stabilizing such a turbine. Throttling devices placed too close to the runner eye bring a marked drop in efficiency and also increase the noise level. A throttle at some distance from the runner eye increases the length of a power unit and can lead to pressure pulsations.

Bypassing a portion of the mass flow at the runner exit is most uneconomical and disturbs the rotationally symmetric entrance condition into the combination chamber.

Both methods must be discounted.

The use of prerotation of the entrance air to alter the compressor head is ideal, as seen from the presented test curves.

With power consumers, coupled to a single turbine or to a few turbines, operating in parallel, various self-regulation characteristics of the load can lead to difficulties in the system regulation. This gas turbine with variable inlet vane position need not be matched to a particular load by changing the regulation characteristics, since the self-regulation of the consumer does not enter the picture. Other advantages are the instantaneous response to a load and a speed practically constant throughout the load range. With conventional regulators, it is possible to achieve constant turbine rpm, but the transient behavior is most undesirable.

Practically constant speed over the load range, immediate response, therefore no adverse transient behavior and an operation independent of the type of load, are the main features of this excellent development.

Authors' Closure

The authors wish to sincerely thank Professor Netsch for the time and effort spent in reviewing and discussing this paper. They appreciate very much the compliments given to them by such an international figure in turbomachinery and its control.

Dr. Netsch's review of the different methods applied to the control of gas turbines, their advantages, and disadvantages is an excellent one.

It is felt that the use of variable geometry configurations has not been fully utilized by the gas turbine technology as compared to the hydraulic turbine technology. It is understandable why designers would shy away from moving parts in high temperature and pressure regions. This then makes the inlet to the compressor an ideal place for varying its geometry. This can be very useful for gas turbines in general, whether they are of the two shaft or single shaft configuration. The movable inlet guide vanes add another degree of freedom to the designer of gas turbines. Hopefully, soon, another paper will be prepared to cover the effect of prewhirl vanes on single shaft gas turbines.

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