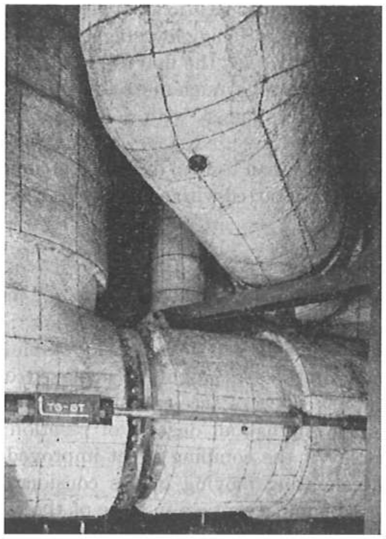

Fig. 15 Large-diameter piping in cellar of two-shaft gas turbine to illustrate the problems of temperature expansion

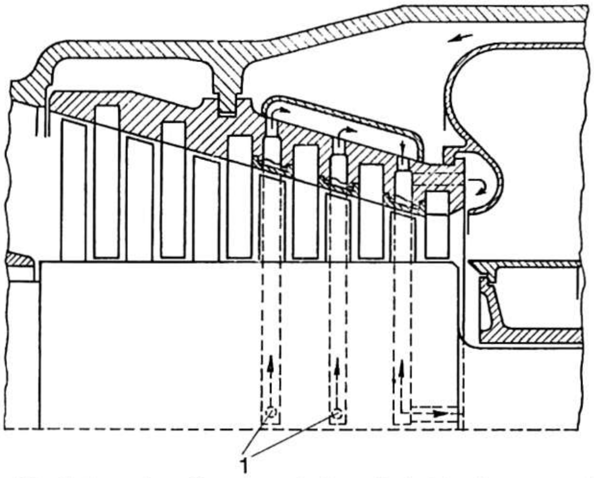

Fig. 16 System of cooling channels to protect stator from excessive temperature. 1—Entrance cooling air near horizontal flange.

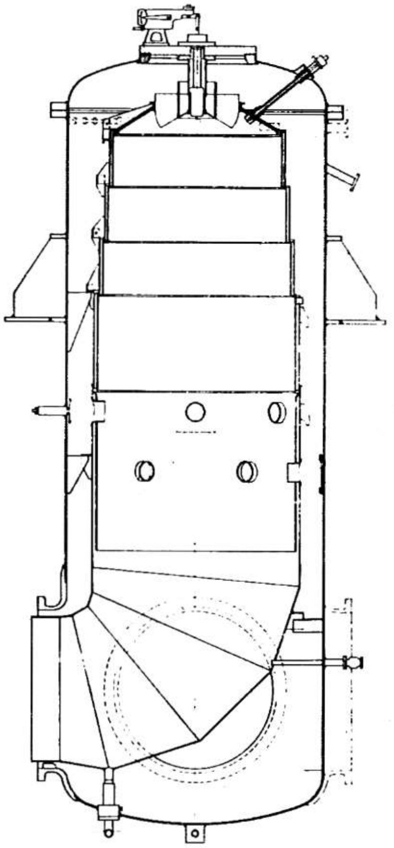

Fig. 17 Section through combustion chamber showing individually adjustable air mixing nozzles

quires a sodium content at least equal to the Va content and consists of the addition of silicate (SiO_2) in various soluble or finely dispersed forms. The apparent paradox between these two methods is explained in Fig. 14, which shows that low and high sodium contents both have higher melting temperatures than some intermediate proportions. Of course, the fuel treatment must also counteract deposits or cause deposits to take an easily removable form; whereas with untreated residual fuels weekly washings were hardly sufficient, a fuel of 350 ppm ash, treated with colloidal SiO_2, has not caused any appreciable output loss in 500 hr operation.

(*c*) Temperature expansion of gas turbine housings, rotors, piping, and combustion chambers amounting to 1 in. and more, must be dealt with and tribute should be paid to the men at the drawing board who, on the first machines, planned their structure so that no trouble whatsoever resulted from this source. The aspect of the piping of a two-shaft gas turbine gives an idea of the problems involved.

(*d*) Since a large portion of air is not required for combustion but is mixed to the core of hot gases on its way from the combustion chamber to the turbine, some of it can be retained to cool vital parts or to provide a screen between the hot gases and the surface to be protected. For instance, the hot gases are kept away from the face of the rotor and from the labyrinths of the shaft. Some cooling air protects the root of the first stationary and moving rows. More elaborate systems are applied or planned to carry cooling air to several stages or to individual blades. Fig. 16 illustrates an example of stator cooling. It must be kept in mind that the cooling air lowers the average temperature of the working gas and affects the cycle efficiency. It is necessary to use it with greatest economy. One trouble was encountered on early gas turbines. In the pipe bend between combustion chamber and turbine, hot gas and air did not mix properly and the first row of guide blades had over and under temperature so that some blades sagged under the gas pressure. The trouble was cured by a set of adjustable mixing nozzles, Fig. 17.

Where gas cooling is no longer adequate, liquid cooling or cooling by evaporation or surface sweating is more efficient. It is not yet known whether very hot combustion gases from residual fuels could sweep intensely cooled surfaces and produce only a very thin layer of slag adherent to the surface, excess slag remaining liquid and being swept off. Water-cooled blades and turbines would be of particular interest for combined gas turbine/steam turbine cycles.

DISCUSSION

K. O. Holliger[1]

In Fig. 3 of the very interesting paper presented by Dr. Seippel, three characteristic layouts of bladings are shown. Detail "a" of the mentioned figure (or some intermediate layout between "a" and "b") represents today's conventional layout for compressors of jet engines. Detail "c" represents Keller's approach to the axial compressor round about 1930. As mentioned by Dr. Seippel, the idea was—and still is—to favor stability in multistage compressors by having accelerated flow in each stator. Industrial compressors of Keller's design have been successfully built ever since and are still being produced today by Escher Wyss Ltd. Measurements have proved that the

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expected combing effect is actually present. In this design, therefore, the performance of a certain stage is only a function of its geometry, the radial distribution of energy upstream of the stage being uniformly good in all stages, thanks to the acceleration in all stators. A stage of given geometry will perform just as well if introduced as stage 16 or as a first stage in such a compressor design.

Theoretically, it can be proved that the highest pressure ratio per stage can be obtained by this design—as long as Mach number is not the critical parameter. In jets, Mach number usually is the criterion, so this design will be of little use for this purpose. For industrial applications, however, the speed of the compressor is usually limited by strength of material considerations in the driving turbine, long before the aerodynamically critical speed for the high reaction compressor has been attained. One must not forget that in a compressor the lower the local overspeed in a blading, the higher the critical Mach number. Low overspeed is obtained by low cambered profiles, the latter being an inherent feature of high reaction compressor designs.

Concerning the efficiency of compressors, the discusser thinks that this is a function of the experience of the builders and not of the degree of reaction.

R. Parker[2]

There is a tendency in the paper and in the oral discussion following its presentation to relate instability to the stage reaction. I would like to point out that the blade stagger angles may be a better basis for comparison. The stagger angle varies with both degree of reaction and the ratio axial velocity/blade velocity, high values of the latter producing low staggers.

It is my experience that, as the flow is reduced below the stall value, the characteristic falls much more sharply with low stagger designs than with high stagger, with a corresponding effect on stability.

In extreme cases, this can lead to difficulty in starting the compressor unless it can be started with a low circuit resistance.

Author's Closure

The degree of reaction R as illustrated in Fig. 2 has provoked a few remarks. I should like to conclude as follows:

While in early days it was feared that stable operation of multistage axial compressors might be achieved only with the help of the combing effects of accelerated flow in the guide vanes, experience has shown that all degrees of reaction down to 0.5 are feasible. Only if the combing effect improved the drag-lift ratio of the decelerating moving blades considerably, would a reaction above 1 be an advantage in spite of the overspeeds due to the unsymmetry of the velocity diagrams. The efficiency of compressor stages is, however, equal or superior today to the efficiency of turbine stages. Therefore, there is no evidence of deteriorated performance of decelerating rows.

If the ratio of deceleration is a criterion of feasibility of a blade row, and if Mach number is not a consideration (as, for instance, when compressing helium or hydrogen), it can be shown that high pressure ratio per stage can be obtained with a degree of reaction of 0.5 as well or better than with a high degree of reaction.

As Mr. Parker suggests, the above considerations can be expressed with the help of stagger angles if this is found convenient.

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