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(54) CROSSOVER DUCT ASSEMBLY PRIMARILY FOR MULTI-STAGE COMPRESSORS

(71) We, THE GARRETT CORPORATION, a Corporation organised under the laws of the State of California, United States of America, of 9851—9951 Sepulveda Boulevard, P.O. Box 92248, Los Angeles, California 90009, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to crossover ducts, primarily for providing communication between adjacent stages of a multiple stage compressor, and to multistage compressors incorporating such crossover ducts.

Multiple stage compressors, such as are used in turbine engines, frequently incorporate one or more centrifugal compressor wheels. Such compressor wheels convert an axially entering gas stream into a radially outwardly directed compressed gas stream. It is therefore necessary to provide a pneumatic crossover duct between adjacent compressor stages to convert the radially outwardly directed gas stream leaving one compressor wheel into an axially directed gas stream for compression by an adjacent wheel. In such crossover ducts aerodynamic considerations are of great importance in that it is desirable to couple adjacent compressor stages so as to cause a minimum of turbulence, pressure losses and efficiency losses.

According to one aspect of the present invention a crossover duct assembly affords an entrance portion, a turning bend, and an exit portion all extending around a common axis and together forming a crossover duct, the entrance portion providing a flow space for a gas flow generally radially outwardly away from the said axis, while the exit portion provides a flow space for a gas flow generally radially inwardly towards the said axis, and the turning bend interconnects the entrance portion and the exit portion to direct a radially outwards gas flow in the entrance portion into the exit portion as a radially inwards gas flow, whereby the flow path of the gas, as seen in any plane which contains the axis and intersects the crossover duct, is generally U-shaped, the crossover duct being bounded on its radially inner side by an inner wall, and on its radially outer side by an outer wall having a first section which extends along the entrance portion and a second section which extends along the exit portion, the inner wall being fastened to the second section of the outer wall by means maintaining a spacing forming the exit portion, the second section of the outer wall being fastened to the first section thereof, and the crossover duct assembly also including, extending across the entrance portion between the inner wall and the first section of the outer wall, to maintain the spacing between the inner wall and the first section of the outer wall, a plurality of diffuser vanes which constitute the only components extending across the gas flow path in the entrance portion.

In the preferred form of the invention, each diffuser vane has a substantially constant thickness along much of its length, and helps to direct the swirling gas flow entering the entrance portion to flow in a radially outward direction. Each diffuser vane may have a leading edge wedge angle of at least 2°, and preferably between 4° and 10°; preferably, the diffuser vanes are mounted at an angle to the radial direction, and that surface of each vane which faces in a direction having a radially inwards component is contoured adjacent the leading edge of that vane to provide the leading edge wedge angle.

The turning bend may have a shape composed of elliptical quadrants, in order to improve flow efficiency and to reduce pressure losses. More specifically, the shape of the inner wall, as seen in section on a plane containing the axis, includes a pair of generally elliptical quadrants each having a ratio of major axis (normal to the said common axis) to minor axis (parallel to the said common axis) of at least 1.20, and the shape of the outer wall, as seen in section on a plane containing the axis, includes a pair of generally elliptical quadrants each having a ratio of major axis (normal to the said common axis) to minor axis (parallel to the said common axis) of at least 1.15.

In the preferred embodiment, the means maintaining the spacing forming the exit portion may comprise a number of deswirl vanes extending between and fastened to the inner wall and the second section of the outer wall. The deswirl vanes serve to reduce the tangential swirl of the compressed gas leaving the turning bend, and thereby to reduce further the pressure losses. The vanes are preferably fastened in position by bolts extending through the deswirl vanes and connecting together the inner wall and the second section of the outer wall.

The first section of the outer wall preferably bounds the entrance portion and at least part of the turning bend. Although in the preferred embodiment the first section extends only halfway around the turning bend, in the direction of gas flow, it is possible for the first section to provide the whole of the outer boundary of the turning bend.

Similarly, the second section of the outer wall preferably bounds the exit portion and at least part of the turning bend. Again, in the preferred embodiment the second section extends only halfway around the turning bend, but it is possible for it to provide the whole of the outer boundary of the turning bend; in this case, of course, the first section would bound the entrance portion, but no other parts of the crossover duct.

The invention also provides, according to a second aspect, a compressor having first and second compressor stages, between which is provided a crossover duct assembly according to the first aspect, the first compressor stage being a centrifugal-flow stage, and directing its output flow into the entrance portion of the duct assembly, and the exit portion of the duct assembly being connected to supply its radially inward gas flow to the gas inlet of the second compressor stage.

The invention may be carried into practice in various ways, but one specific example will now be described by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a perspective view of part of a turbine engine, broken away to show a crossover duct embodying the present invention;

Figure 2 is an enlarged section through part of the crossover duct;

Figure 3 is an enlarged vertical section taken on the line 3—3 of Figure 2, showing diffuser vanes in the crossover duct;

Figure 4 is an enlarged elevation view of a portion of one of the diffuser vanes;

Figure 5 is an enlarged vertical section taken on the line 5—5 of Figure 2; and

Figure 6 is an enlarged view corresponding to part of Figure 2.

A turbine engine 10 is shown in Figure 1, and generally comprises a cylindrical engine housing 12 in which is mounted a longitudinally extending power shaft 14. The housing 12 has its forward end 16 flared outwardly to form an open air inlet 18 for the passage of air through a compressor having two stages 20 and 22. The compressor stages 20 and 22 comprise centrifugal compressor wheels 24 and 26, respectively, mounted on the power shaft 14. Alternatively, the second compressor 22 may be an axial-flow compressor if desired. In operation, air is drawn in through the inlet 18 by the first centrifugal compressor wheel 24 and is compressed and discharged radially outwardly into a crossover duct 28. The crossover duct 28 serves to turn the radially outwardly directed air to a radially inward direction for axial supply to the second compressor wheel 26. The second wheel 26 further compresses the air, and discharges the air outwardly through a duct 30 leading to a combustion chamber 32. In the combustion chamber 32, the air is mixed with a suitable fuel and the resulting mixture ignited, whereupon the hot exhaust products are directed through a duct 34 to drive a series of turbine wheels 36 mounted on the shaft 14. Output from the engine may be taken via a gear 38 on the shaft 14, or, alternatively, in the form of thrust as in a jet propulsion aircraft engine.

As shown in Figure 2, the first compressor wheel 24 comprises a plurality of forward-facing impeller blades 40 formed integrally with a circular backing plate 42. The plate 42 and a shroud 43 mounted on the engine housing 12 together form a chamber 44 for the first compressor stage 20.

The crossover duct 28 comprises a continous annular passage provide flow communication between the two compressor stages 20 and 22. More specifically, the crossover duct 28 has a gas entrance portion defining a radially outwardly directed gas flow path 45 blending into a generally U-shaped turning bend 47 for turning the swirling, radially outwardly directed gas flow back toward a radially inward direction. The turning bend 47 in turn blends with a gas exit portion defining a radially inwardly directed gas flow path 46 which guides the compressed gas flow inwardly toward the second compressor wheel 26. In the present example, as Figure 2 shows, the radially inwardly directed flow path 46 terminates in an axially turned portion 49 for supplying the compressed gas axially to the second compressor wheel 26.

The gas entrance portion of the crossover duct 28 comprises an annular inner wall 48 and an annular outer wall 50. The walls 48 and 50 are spaced from each other to form the radially outward flow path 45, and a plurality of circumferentially spaced thin diffuser vanes 52 are supported between the walls 48 and 50, as shown in Figures 2 to 4. These vanes 52 each have tabs 54 on opposite sides received in pre-formed slots 56 in the walls 48 and 50. Alternatively, the diffuser blades 52 might be mounted between the walls 48 and 50 by other techniques such as brazing. Finally, the outer wall 50 includes a plurality of circumferentially spaced, exterior bosses 58 into which bolts 60 are threaded to secure the entire gas entrance portion to the engine housing 12, and to align the walls 48 and 50 to receive the compressed air discharged from the first compressor stage 20.

As shown in Figures 3 and 4, the diffuser vanes 52 are angularly set with respect to the radially outward direction of air flow through the crossover duct 28. The angular positions of the diffuser vanes 52 are selected to assist in turning the swirling compressed air flow leaving the first compressor wheel 24 to flow in a radially outward direction, and to help remove circumferential components of air velocity. The diffuser vanes are thin, and as Figure 4 shows, the part of each diffuser vane adjacent its leading edges 62 is tapered to form a leading edge wedge angle θ of at least two degrees, and preferably between four and ten degrees. This taper is formed entirely on the suction surfaces 65 of the vanes, as a contoured surface portion 64; there are no angled portions on the pressure surfaces 66 of the vanes. The thin vanes have a length of the order of seventy-five times their maximum thickness, and the leading edge 62 of each vane is formed to have a rounded nose 63 preferably having a thickness of about one-half the vane thickness. In the present example, the contoured surface 64 is generally a portion of an ellipse, although it may approach a straight line configuration. This shaping of the diffuser vane leading edges has been found to improve the smoothness of air flow through the crossover duct by reducing the incidence of air flow upon the vane suction surface, and has been found to work equally well with single and multiple-row diffuser vane constructions.

As shown in Figure 2, the inner and outer walls 48 and 50 of the duct extend radially outwardly, parallel to one another, from the compressor wheel 24, and then curve together into the turning bend 47 to form one-half, or about 90°, of the turning bend. The inner and outer walls 48 and 50 include shaped ends 67 and 68 for matingly engaging and abutting two walls 69 and 70 forming, respectively, the inner and outer walls of the remainder of the turning bend 47 and of the radially inward flow path 46, and thereby forming the remainder of the continuous, U-shaped duct passage.

The inner and outer walls 69 and 70 of the duct exit portion are maintained in a predetermined parallel spatial relationship by a plurality of circumferentially spaced deswirl vanes 72. More specifically, as shown in Figure 5, each deswirl vane 72 comprises an elongate crescent-shaped strip of metal or the like having a thickness decreasing from its centre towards both ends. The vanes 72 each have an arcuate shape, and are positioned between the walls 69 and 70 by mounting bolts 74 and positioning bolts 75. The mounting bolts 74 are received through the centres of said vanes, and through performed holes 76 in the walls 69 and 70, and are then threaded into bosses 78 formed on the outside of the inner wall 48 of the duct entrance portion (Figure 2). The positioning bolts 75 are received through the exit portion outer wall 70, and are threaded into the vanes 72 near the ends of the vanes. In this manner, deswirl vanes 72 are accurately positioned between the walls 69 and 70, with the exit portion of the crossover duct 28 securely fastened to the inner wall 48 of the entrance portion. Finally, the duct outer walls 50 and 70 are connected together by bolts 71 received through flanges 73 to complete a rigid crossover duct construction. Alternatively, if desired, the deswirl vanes 72 may be mounted on either or both of the walls 69 and 70 by other methods such as brazing, or they may be moulded integrally with either of the walls 69 and 70.

The turning bend 47 of the crossover duct 28 is shaped for optimum efficiency of air passage without substantial turbulence or pressure loss. As shown in Figure 6, the inner wall 48 is shaped to form one quadrant of an ellipse having major and minor half-axes identified in Figure 6 by the letters (A) and (B), and the inner wall 69 is shaped to form a second quadrant of an ellipse having major and minor half-axes identified by the letters (C) and (D). Together, the inner walls 48 and 69 form a continuous, semi-elliptical configuration forming the inner wall of the turning bend 47. In a similar manner, the outer wall 50 is shaped to form one quadrant of an ellipse which blends into a second quadrant formed by the exit portion outer wall 70. The major and minor half-axes of the outer wall quadrants are identified by the letters (E) and (F), and (G) and (H), respectively. For optimum aerodynamic performance, the ratio of the major and minor axes of the inner wall elliptical quadrants is at least 1.20, and the ratio of the major and minor axes of the outer wall elliptical quadrants is at least 1.15.

These ratios have been found to provide relatively elongated turning bend wall geometries, which reduce deleterious boundary layer effects through the turning bend, and thereby reduce crossover duct pressure losses. The crossover duct described above is easily assembled with all components maintained in the desired aerodynamically optimum position. The inner wall sections 48 and 69, which may be formed as a single component, are bolted onto the exit portion outer wall section 70 by means of the bolts 74 with the deswirl vanes 72 in the desired position. Then, this subassembly is fixed to the entrance portion outer wall section 50 by means of the bolts 71 to provide a rigid duct assembly, with the thin diffuser vanes 52 properly supported in the desired position. Finally, the entire duct assembly is secured to the engine housing by the bolts 60.

It should be understood that various modifications are possible, and also that the duct may be used wherever it is necessary to turn a swirling gas flow smoothly and efficiently from a radially outward to a radially inward direction.

WHAT WE CLAIM IS:—

1. A crossover duct assembly affording an entrance portion, a turning bend, and an exit portion all extending around a common axis and together forming a crossover duct, the entrance portion providing a flow space for a gas flow generally radially outwardly away from the said axis, while the exit portion provides a flow space for a gas flow generally radially inwardly towards the said axis, and the turning bend interconnects the entrance portion and the exit portion to direct a radially outwards gas flow in the entrance portion into the exit portion as a radially inwards gas flow, whereby the flow path of the gas, as seen in any plane which contains the axis and intersects the crossover duct, is generally U-shaped, the crossover duct being bounded on its radially inner side by an inner wall, and on its radially outer side by an outer wall having a first section which extends along the entrance portion and a second section which extends along the exit portion, the inner wall being fastened to the second section of the outer wall by means maintaining a spacing forming the exit portion, the second section of the outer wall being fastened to the first section thereof, and the crossover duct assembly also including, extending across the entrance portion between the inner wall and the first section of the outer wall, to maintain the spacing between the inner wall and the first section of the outer wall, a plurality of diffuser vanes which constitute the only components extending across the gas flow path in the entrance portion.

2. A duct assembly as claimed in Claim 1, in which the first section of the outer walls bounds the entrance portion and at least part of the turning bend.

3. A duct assembly as claimed in Claim 1, in which the second section of the outer wall bounds the exit portion and at least part of the turning bend.

4. A duct assembly as claimed in Claim 1, in which the first section of the outer wall bounds the entrance portion and part of the turning bend, and the second section of the outer wall bounds the exit portion and part of the turning bend.

5. A duct assembly as claimed in any of the preceding claims, in which the means maintaining the spacing forming the exit portion comprises a number of deswirl vanes extending between and fastened to the inner wall and the second section of the outer wall.

6. A duct assembly as claimed in Claim 5, in which each deswirl vane is generally crescent-shaped.

7. A duct assembly as claimed in Claim 5 or Claim 6, in which the deswirl vanes are fastened in position by bolts extending through the deswirl vanes and connecting together the inner wall and the second section of the outer wall.

8. A duct assembly as claimed in Claim 7, in which each deswirl vane is fastened in position by a single respective one of the bolts, and also by means preventing rotation of the deswirl vane about its fastening bolt.

9. A duct assembly as claimed in any of the preceding claims, in which each diffuser vane has a leading edge wedge angle of at least 2°.

10. A duct assembly as claimed in Claim 9, in which the leading edge wedge angle of each diffuser vane is between 4° and 10°.

11. A duct assembly as claimed in Claim 9 or Claim 10, in which the diffuser vanes are mounted at an angle to the radial direction, and that surface of each vane which faces in a direction having a radially inwards component is contoured adjacent the leading edge of that vane to provide the leading edge wedge angle.

12. A duct assembly as claimed in any of the preceding claims, in which the length of each diffuser vane, in the flow direction, is at least seventy-five times its maximum thickness.

13. A duct assembly as claimed in any of the preceding claims, in which the shape of the inner wall, as seen in section on a plane containing the axis, includes a pair of generally elliptical quadrants each having a ratio of major axis (normal to the said common axis) to minor axis (parallel to the said common axis) of at least 1.20, and the shape of the outer wall, as seen in section on a plane containing the axis, includes a pair of generally elliptical quadrants each having a

ratio of major axis (normal to the said common axis) to minor axis (parallel to the said common axis) of at least 1.15.

14. A duct assembly as claimed in Claim 13, in which one of the second-mentioned pair of elliptical quadrants is formed by the first section of the outer wall, while the other elliptical quadrant of that pair is formed by the second section of the outer wall.

15. A duct assembly as claimed in any of the preceding claims, in which the inner wall has a first section which extends along the entrance portion, and a second section which extends along the exit portion.

16. A duct assembly as claimed in either of Claims 13 and 14 and Claim 15, in which one of the first-mentioned pair of elliptical quadrants is formed by the first section of the inner wall, while the other elliptical quadrant of that pair is formed by the second section of the inner wall.

17. A duct assembly as claimed in Claim 15 or Claim 16, in which the means fastening the inner wall to the second section of the outer wall also fastens together the first and second sections of the inner wall.

18. A duct assembly as claimed in Claim 17 when appendant to Claim 7, in which the bolts connecting together the second section of the outer wall and the inner wall pass through the second section of the inner wall into threaded bosses on the first section of the inner wall.

19. A duct assembly as claimed in any of the preceding claims, in which the first and second sections of the outer wall are provided with exterior flanges, and are fastened together by bolts through the flanges.

20. A duct assembly as claimed in any of the preceding claims, in which the inner and outer walls have, along the entrance portion, openings which receive tabs formed on the diffuser vanes, to mount the diffuser vanes in the entrance portion.

21. A compressor having first and second compressor stages, between which is provided a crossover duct assembly as claimed in any of the preceding claims, the first compressor stage being a centrifugal-flow stage, and directing its output flow into the entrance portion of the duct assembly, and the exit portion of the duct assembly being connected to supply its radially inward gas flow to the gas inlet of the second compressor stage.

22. A crossover duct substantially as herein described with reference to Figures 2 to 6 of the accompanying drawings.

23. A multiple stage compressor substantially as herein described with reference to Figure 1 incorporating a crossover duct substantially as herein described with reference to Figures 2 to 6 of the accompanying drawings.

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Agents for the Applicants.

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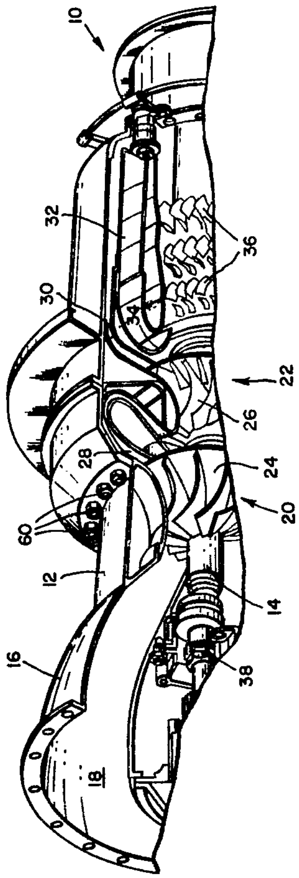

Fig. 1.

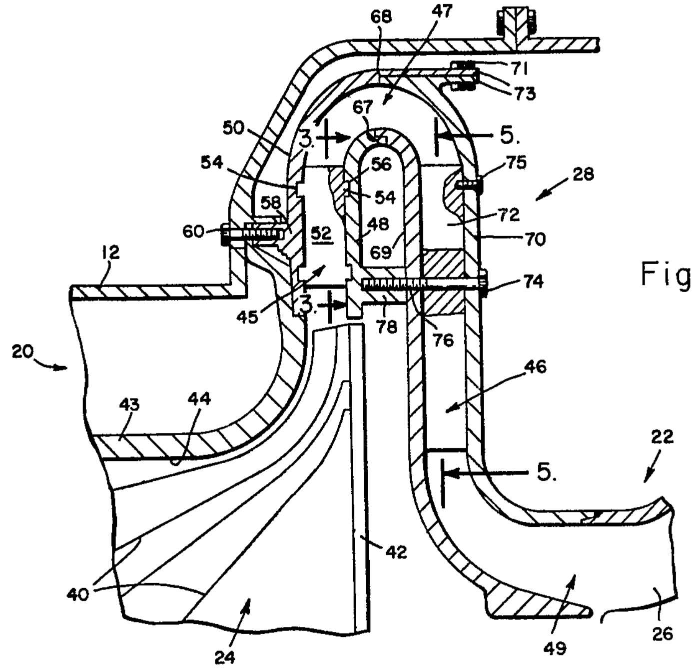

Fig. 2.

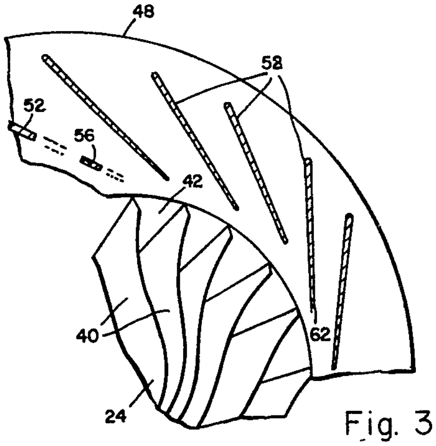

Fig. 3.

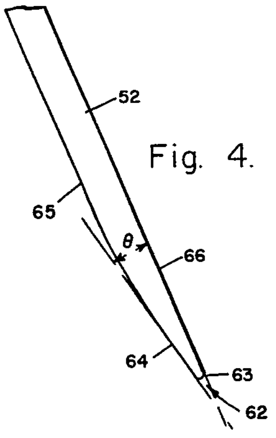

Fig. 4.

Fig. 5.

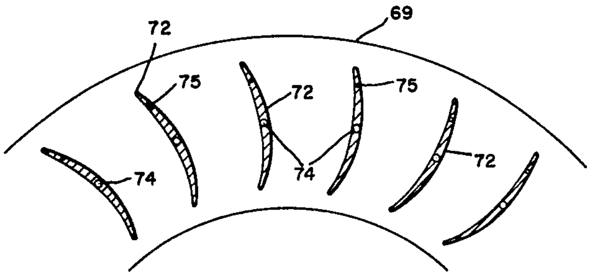
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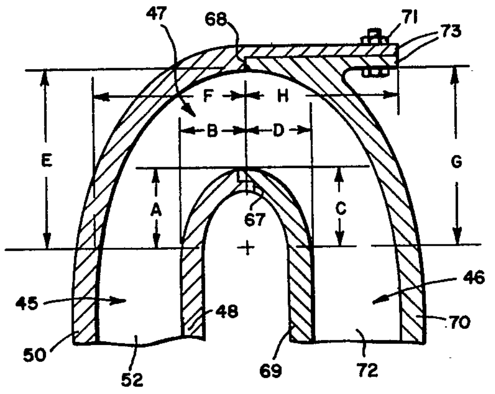
Fig. 6.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