April 5, 1955 R. RIGBY 2,705,615

ROTARY REGENERATIVE HEAT EXCHANGER WITH SHUTTERS

Filed April 22, 1952 4 Sheets-Sheet 1

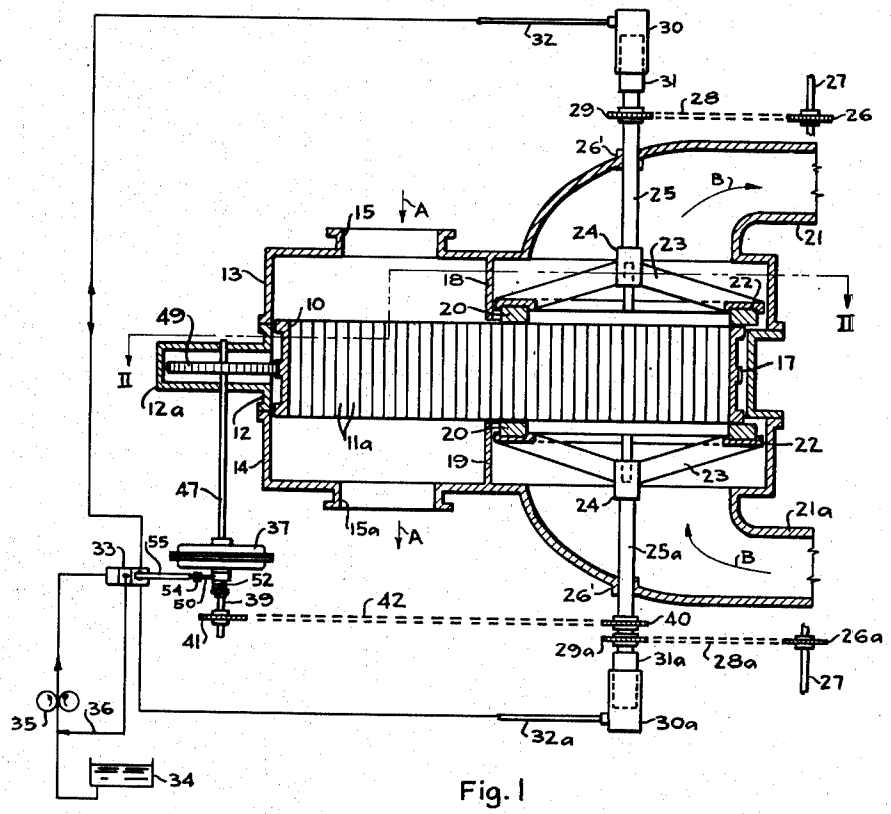


Fig. 1

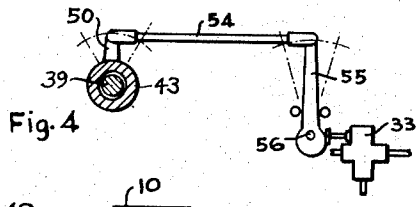


Fig. 4

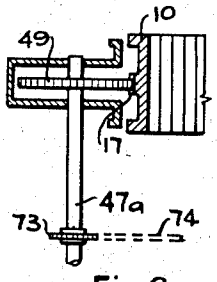


Fig. 8

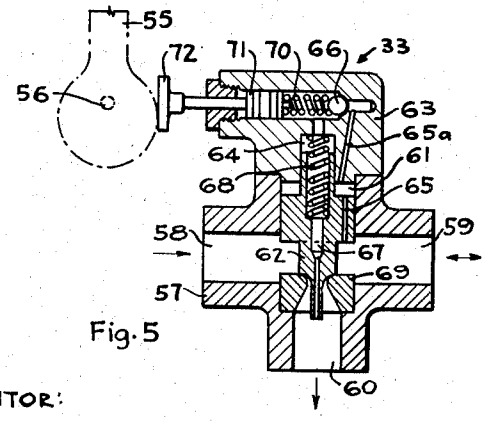


Fig. 5

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ROTARY REGENERATIVE HEAT EXCHANGER WITH SHUTTERS

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4 Sheets-Sheet 2

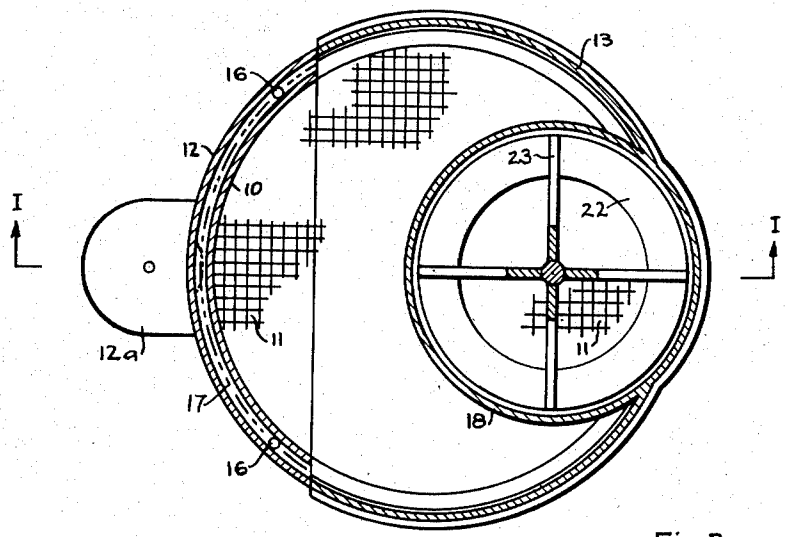


Fig. 2

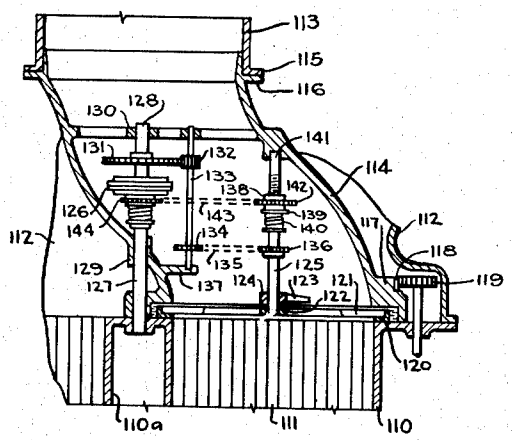


Fig. 10

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ROTARY REGENERATIVE HEAT EXCHANGER WITH SHUTTERS

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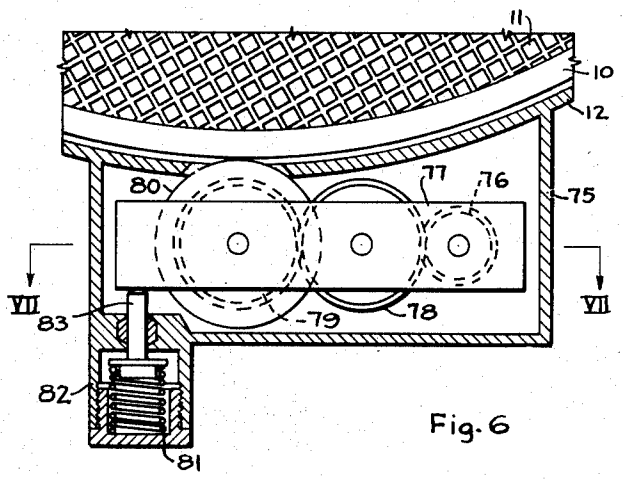


Fig. 6

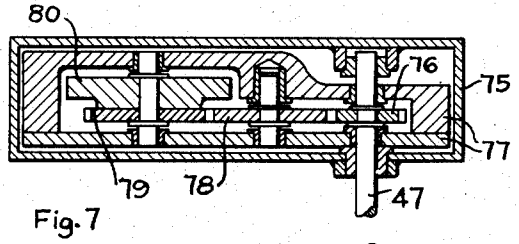


Fig. 7

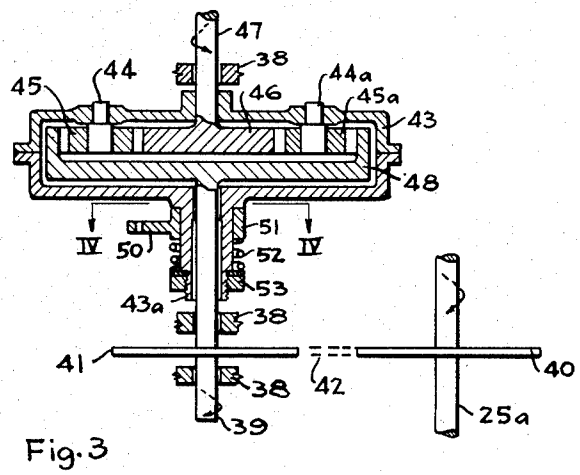


Fig. 3

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ROTARY REGENERATIVE HEAT EXCHANGER WITH SHUTTERS

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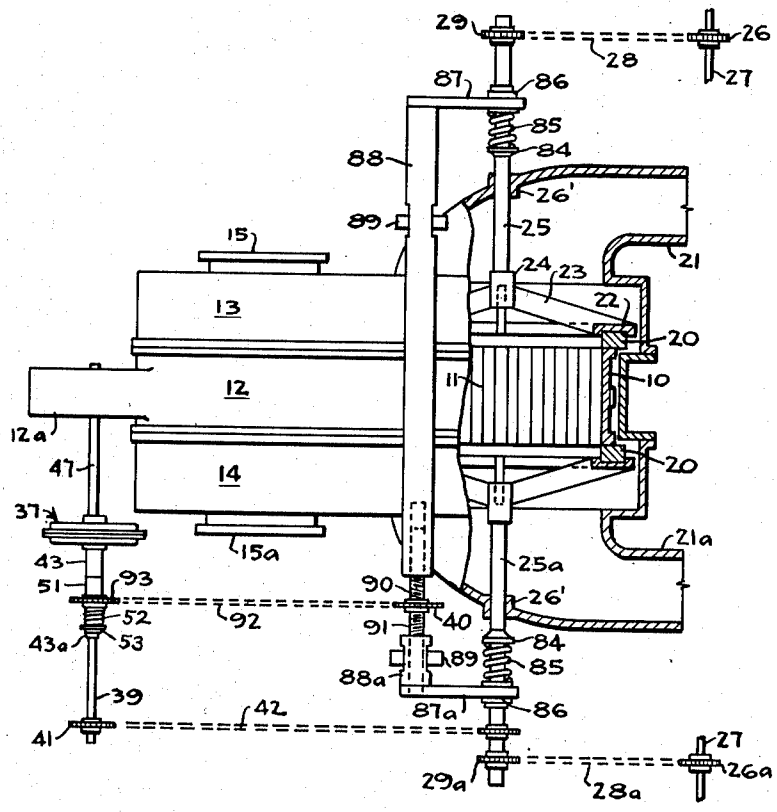


Fig. 9

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United States Patent Office

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Patented Apr. 5, 1955

2,705,615

ROTARY REGENERATIVE HEAT EXCHANGER WITH SHUTTERS

Richard Rigby, Great Crosby, Liverpool, England, assignor to Shell Development Company, Emeryville, Calif., a corporation of Delaware

Application April 22, 1952, Serial No. 283,569

Claims priority, application Great Britain April 24, 1951

18 Claims. (Cl. 257—6)

This invention relates to a regenerative heat exchanger of the kind in which the heat-accumulating packing is contained in or constituted by a matrix consisting of a plurality of separate, longitudinal matrix ducts arranged in a matrix drum, usually parallel to one another, the ends of the ducts forming end contact faces which are swept by ring-shaped shutters mounted in fluid-sealing contact with these end faces and rotatable about the common axis of the shutters, which axis is offset from that of the drum, the interiors of the shutters being in constant communication with end ports of first or inner conduits for the flow of one of the heat-exchanging fluids and their exteriors being in constant communication with second or outer conduits for the flow of the other heat-exchanging fluid. Sweeping of the end faces of the matrix is effected by relative motion between the matrix drum and the shutters about the central axis of the drum, either by rotating the drum while keeping the said common axis of the shutters fixed or by keeping the drum stationary and moving the said common axis of the shutters and the termini of the first or inner conduits along a closed path, e. g., a circular path, about the central axis of the drum whereby the shutters sweep both faces with coordinated movements. Such heat exchangers, which are hereinafter referred to as "regenerative heat exchangers of the kind specified," are described, for example, in my U. S. Patent No. 2,578,945.

As applied, for example, for use in gas turbine plants, the hot exhaust gas from the turbine is caused to flow through the outer conduits and through the ducts of the matrix the termini of which are, for the moment, outside the area enclosed by the shutters and the cold compressed working medium is caused to flow through the inner conduits and through the matrix ducts that then have their termini inside the shutter areas. The hot and cold heat-exchanging media are often at a high pressure difference, and the rotatability of the shutters on their own axis is intended to enable them to form and maintain a mating relationship between themselves and the drum faces such as will insure a seal which can stand up to the pressure differences involved.

As illustrated for example in Figures 1–5 and 8 of my aforesaid patent, in such regenerative heat exchangers the matrix drum may be stationary and the eccentric shutter supports (e. g., eccentric spindles driven by a crank or supported within the ports of crank-shaped rotatable inner ducts) may be swept in unison over the two end contact faces of the matrix drum in such a manner that the common axis of the shutters moves in a closed path, such as a circular path, surrounding the central axis of the matrix drum at a suitable angular sweep velocity, the shutters being mounted for rotation about their common, eccentric axis separately from the said angular sweeping motion; or, as illustrated in Figure 7 of the said patent, the central axis of the matrix drum and the position of the shutter supports may both be kept stationary and both the drum and shutters may be rotated about their respective axes, the rotation of the drum thereby producing the relative sweeping motion and the angular speed of the drum being the angular sweep velocity which is separate from and differs from the angular velocity of the shutters, so that there is again a relative rotation between the drum and the shutters. In the former case rotation of the shutter rings relative to the drum about their own common axis, which is essential to insure even wear so as to form and maintain a mating relationship with the matrix drum and

to insure fluid-sealing contact between the shutter and the matrix face, is induced by the frictional forces exerted by the shutter and matrix faces during the sweeping motion, the latter being induced positively by rotating the shutter supports. In the latter case, a similar relative sweeping motion occurs which may be induced in either of two ways: the matrix drum may be rotated by a suitable power drive and the shutters may be induced to rotate about their own axis by frictional contact with the faces of the positively driven matrix drum; or, one or both of the shutters may be rotated about their axis by the power drive and the matrix drum may be induced to rotate at a different speed by frictional forces between the shutter or shutters and the drum. The instant invention is applicable to both of these cases, which have in common the circumstance that the shutters rotate about their own axis at angular shutter velocities that are separate from the angular sweep velocity (in the sense that they are not constrained by drive elements to rotate at any set ratio of angular velocities) but are yet related by the frictional drag occurring between them.

While for simplicity in description reference is made herein to a common axis of the ring-shaped shutters, it should be understood that this is strictly correct only in the usual case, to be illustrated, wherein the end contact faces of the matrix drum are both perpendicular to the drum axis and the matrix ducts run parallel to the drum axis; it will be appreciated that the invention may be applied to other, equivalent arrangements of the matrix drum, wherein the end faces are not necessarily perpendicular to the drum axis or the matrix ducts are not necessarily parallel to the drum axis, and that suitable modifications in the geometry will occur to those skilled in the art to satisfy the requirement that the two shutters rotate in the planes of their respective end contact faces and that the two shutters at all times surround the termini of the same variable group of matrix. Further, the invention is not limited to constructions employing only one shutter at each end of the matrix drum.

Owing to the wear on the shutters and/or on the end contact faces of the matrix drum which occurs in normal use, the intimacy of contact of the ring-shaped shutters on the contact faces and, hence, the efficiency of the fluid seal, is liable to diminish. For the same reason the ratio of the angular shutter velocities to the angular sweep velocity is liable to vary. Thus, when the shutters are positively driven, the ratio of the angular shutter velocity to the rotational speed of the matrix (equal to the sweep velocity when the positions of the shutter supports are stationary) will tend to increase with wear while, when the matrix drum is positively driven, the same ratio of angular velocities will tend to diminish with wear.

In this specification and claims, the ratio of the positively induced angular velocity to the frictionally induced angular velocity is designated the "induced velocity ratio." Thus, when the drum is stationary and the supports for the shutters are swept about the drum axis by positive drive, the designated ratio is the ratio of the angular sweep velocity to the angular shutter velocity; this is true also when a rotary matrix drum is positively rotated and the shutter supports remain stationary. However, when the shutters are positively rotated about their common axis and the drum is induced to rotate by frictional contact with the shutters, the designated ratio is the ratio of the angular shutter velocity to the angular sweep velocity.

Both the leakage of heat-exchanging fluid between the shutters and the matrix drum contact faces, and the induced velocity ratio, are functions of the pressure exerted by the shutters on the matrix contact faces. Underlying the present invention is the circumstance that these functions are so related that at induced velocity ratios below a more or less well-defined critical value, the leakage is small and does not vary greatly with the said induced velocity ratio, while above this critical induced velocity ratio, the leakage tends to increase rapidly with increasing ratios. As the frictional force exerted by the shutters on the matrix drum is equal and

opposite to that exerted by the matrix drum on the shutters, similar critical velocity ratios exist in the two cases mentioned above, viz., using shutters that are freely rotatable and driven frictionally from a positively driven matrix drum or by a positive sweeping motion of their supports over a stationary drum on the one hand, or using a freely rotatable matrix drum that is driven frictionally by shutter rings that are positively driven on the other hand. Similar ratios exist also for the hybrid case wherein only one of the shutters is positively driven and the matrix drum is induced to rotate by frictional contact of one contact face thereof with the shutter, the other shutter being, in turn, driven rotationally by frictional contact with the other face of the matrix drum. In consequence, it is found that the foregoing relationship involving a critical induced velocity ratio applies irrespective of the means employed for generating the sweep and shutter velocities.

According to the main feature of the present invention, in a regenerative heat exchanger of the kind specified the pressure between the matrix drum and the shutter is controlled so as to effect the proper fluid seal without imposing so great a pressure as to cause excessive friction and wear, by providing a variable pressure device. In the preferred embodiment this is effected by positively driving some parts of the exchanger, less than all, rotationally so as to induce positively either the angular sweep movement or the angular shutter movement; inducing rotation to a member not positively driven by friction between at least one shutter and the end contact faces of the matrix drum contiguous thereto; sensing the induced velocity ratio; and varying the pressure between the shutters and the contact faces of the drum in accordance with the sensed induced velocity ratio. The sensing is conveniently effected by providing a sensing device responsive to the relative magnitudes of the angular sweep velocity and the angular shutter velocity and connecting it to control the variable pressure device to increase the said pressure if the induced velocity ratio rises above a predetermined value and, preferably, to decrease the said pressure upon a decrease in the said ratio. Such an increase in pressure increases the intimacy of contact to perform the double function of restoring (i. e., decreasing) the induced speed ratio and reducing the rate of leakage. If the said predetermined value of the induced velocity ratio is the same, or substantially the same as the aforesaid critical value, the leakage is maintained at the low value associated with induced velocity ratios below the critical value.

While it is not essential for the purpose of maintaining the sealing contact and mating relationship, that the pressure be reduced when the induced velocity ratio is less than the critical value, it is advantageous to provide a variable pressure device that can act in this sense also. In this way the wear of the contact faces, and also the power required to drive the positively-driven member, are reduced to a minimum. Moreover, in the case of a regenerative heat exchanger wherein the shutters are positively driven, a reduction in the induced velocity ratio, i. e., a rise in the angular sweep velocity of the drum beyond a designated value may impair the heat transfer efficiency; this may be prevented by this arrangement.

The pressure of the shutters on the contact faces of the matrix drum may be exerted, for example, by a spring or a pneumatic or hydraulic device, the last of these being generally the most convenient. The means for sensing the induced velocity ratio and controlling this pressure in accordance with the invention may comprise a differential gear in which one wheel is driven by the matrix drum or by the supports that cause the shutters to sweep the matrix drum and another wheel is driven by the rotation of the shutters about their axis, so as to form a differential speed-responsive mechanism adapted to actuate a device of known kind for controlling the loading of the spring or the pneumatic or hydraulic pressure, as the case may be. The differential gear is sensitive to any change of speed of one wheel relative to the other and the resulting reaction may be transmitted to the variable pressure control device by any suitable means, for example, mechanical, electrical, pneumatic or hydraulic. Where such a mechanism is used in the present invention, the speed setting will preferably be the aforesaid critical induced velocity ratio. In one particular model which was subjected to test, this critical induced velocity ratio was about 4:5, but the invention may obviously be applied to heat exchangers wherein other induced velocity ratios are maintained.

If the matrix drum is the positively-driven member, it will generally be necessary to locate the drive at the periphery of the matrix drum. Where, as is usually the case, this location is at a comparatively high temperature, it is preferred to provide a positive drive for the shutters. For this purpose, and also for the purpose of applying pressure on the shutters, each of the shutters may be provided with a shaft extending from the hub of the shutter through an opening in a bend or elbow in the duct for the heat-exchanging fluid communicating with the interiors of the shutters.

Whichever member or members is or are not positively driven is or are mounted so as to be freely rotatable with a minimum of friction other than the friction between the shutters and the end contact faces of the matrix. Owing to the difficulty of providing low-friction bearings for the support rollers at the periphery of the drum, where this is the non-positively rotated member, bearings at this location may themselves be mounted so as to be frictionally driven at a speed corresponding with the desired angular velocity of the drum or sweep velocity.

According to a further feature of the invention in a regenerative heat exchanger of the kind specified wherein the axes of the shutters sweep about the central axis of stationary matrix drum, means actuated in dependence upon the angular sweep velocity are provided for controlling the pressure between the shutters and the respective matrix drum faces so as to increase the said pressure if the said speed rises above a predetermined value.

The invention will now be described in more detail by reference to the accompanying drawings forming a part of this specification and illustrating certain preferred embodiments of the invention, wherein:

Figure 1 is a longitudinal sectional view of a regenerative heat exchanger taken on a horizontal section plan indicated by the line I—I of Figure 2, certain auxiliary equipment being shown diagrammatically;

Figure 2 is a transverse sectional view taken on the broken line II—II of Figure 1;

Figure 3 is an enlarged sectional plan view showing the differential gearing coupled to the rotating shutters and the drum;

Figure 4 is a sectional view taken on the line IV—IV of Figure 3 but on a reduced scale;

Figure 5 is a longitudinal sectional view of a valve mechanism forming a part of the hydraulically operated servo-system shown in Figures 1 and 4;

Figure 6 is a fragmentary transverse sectional view of a heat exchanger taken on a vertical section plane showing a modified arrangement for coupling the differential gearing to the rotatable matrix drum;

Figure 7 is a horizontal sectional view taken on the line VII—VII of Figure 6;

Figure 8 is a fragmentary plan section showing a modified drive arrangement for the rotatable matrix drum;

Figure 9 is a plan view of a modified embodiment showing a spring arrangement for loading the shutters; and

Figure 10 is a fragmentary longitudinal sectional view of a regenerative heat exchanger according to the invention wherein the matrix drum is stationary.

Referring first to Figures 1 and 2 of the drawings, the heat exchanger comprises a cylindrical or drum-shaped casing **10** of a circular cross section in which is mounted a matrix **11** consisting of a honey-comb of separate, parallel ducts **11***a* which extend longitudinally parallel to the central axis of the drum and which are in this embodiment, arranged to fill the entire cross-sectional area of the drum. These ducts terminate in plane end contact faces and may have any desired cross-sectional shape, e. g., square as shown in Figure 2 or as shown in my aforesaid U. S. Patent No. 2,578,945. Each duct may contain a packing (not shown) of heat-accumulating material, for example, wire gauze, wire wool or the like. One specific arrangement of such heat accumulating material is disclosed in the copending application of Tipler, Serial No. 209,037, filed February 2, 1951 and now Patent No. 2,622,850, granted December 23, 1952. The matrix drum **10** is mounted so as to be rotatable about its central horizontal axis within the center section **12** of a fluid-tight casing comprising, in addition, end sections **13** and **14**; the latter have openings **15**, **15***a*, to which pipes carrying one of the heat exchanging fluids may be connected. The casing thus forms a pair of outer conduits com-

municating with the termini of certain of the ducts 11*a*. The drum may be mounted on support rollers 16 and an annular gear rack 17 is fixed to the drum for rotation therewith. Fixed within the casing sections 13 and 14, e. g., cast integrally therewith, and situated substantially tangentially to the interior walls, are cyclindrical inner shutter conduits 18 and 19 having circular cross sections and a diameter equal to about half that of the outer casing. The shutter conduits have their ports adjacent the end faces of the drum 10, said ports being situated eccentrically to the central axis of the drum and extending over only minor parts of the areas of said end faces. The ports of the shutter conduits are of equal size and are in alignment to surround the termini of the same variable partial group of matrix ducts; they form shutter supports for the shutters 20, described below. When the drum 10 is rotated there results a relative sweeping rotary motion between the drum and the shutter supports and different matrix ducts are included in the said partial group. The shutter conduits 18 and 19 communicate with pipes 21 and 21*a*, respectively, for the flow of a second heat-exchanging fluid.

In use, one of the heat-exchanging fluids is caused to flow through outer conduits or casing sections as indicated by the arrow A and the other fluid is passed through shutter conduits 18 and 19, preferably in counter-current as indicated by the arrow B. The regenerator is particularly useful for use in gas turbine plants, in which case the fluid flowing through outer conduits is the hot exhaust gas from the turbine, while that flowing through inner shutter conduits is the cool air flowing from the compressor to the combustion chamber. It will be appreciated that the air is in such a case at a much higher pressure than the gas, and that it is therefore of importance to provide an adequate seal between the rotating matrix and the stationary conduits 18 and 19. For this purpose, as described in the aforesaid patent, a ring-shaped shutter 20 is mounted within each of the shutter conduits. Each shutter has a flat, annular sealing face that bears on one of the plane end contact faces of the matrix drum and is of sufficient width to span the full cross-section of the end of one duct 11*a*. Each shutter is fixed on a supporting frame forming the shutter support proper and having an annular back-up ring 22 that is axially and rotationally movable within the respective shutter conduit and is externally in fluid-tight relation to the shutter conduit. The shutters 20 are thereby positioned within the shutter conduits but may likewise be moved axially and rotated about their common axis. Each supporting frame has spokes 23 connecting the back-up ring to a central hub which is secured to a rotatable and axially movable shutter shaft 25 or 25*a* that extends out of the casing through a fluid-tight seal in housing 26'. The connections between the hub and shafts transmit axial thrust and torque about the common axis of the shafts but is loose enough to permit a slight tilting or canting of the supporting frame, which enables the shutters 20 to rock with respect to the shafts with any wear or disturbance between the shutter faces and the contact faces of the matrix drum. The periphery of the drum 10 may be sealed to the casing 12 to prevent by-passing of gas, e. g., by running seals.

The shutter rings 20 are forced into contact with the matrix faces by the differential pressure between the heat-exchanging fluids when the pressure in the shutter conduit exceeds that in the outer part of the casing; however, the invention is not limited to such a relation between the pressures of the heat-exchanging fluids because positive means are provided, as described below, for urging the shutters against the matrix drum. It is evident that rotation of the shutter shafts 25 and 25*a* and the shutters 20 causes a relative rotary motion between the shutters and the matrix drum as the latter is rotated about its own axis; this causes the shutters to "grind in" on the matrix faces and a mating relationship between the surfaces of the rings and the matrix drum is formed and maintained. This grinding and sealing action is facilitated by the aforesaid loose connection between the shafts and shutter support frames, which facilitates the mating of the said surfaces and thereby promotes the maximum avoidance of leakage of fluid medium from the shutter ducts to the space served by the outer part of the casing 12—14.

Suitable means are provided for rotating the coaxial shutter shafts 25, 25*a* at a common speed; this may, for example, include a pair of sprockets 26, 26*a* on a common drive shaft 27 connected by sprocket chains 28, 28*a* to sprockets 29, 29*a*, respectively, on the shutter shafts. It may be noted that only a limited axial movement of the shutter shafts, too small to interfere with the proper operation of the sprocket drives, occurs in the operation of the heat exchanger. Friction of the shutters 20 on the contact faces of the matrix drum causes the latter to be rotated when the drive shaft 27 is turned. The ratio of the positively induced angular velocity of the shutter rings 20 to the frictionally induced angular velocity of the matrix drum 10 is, in this embodiment, the induced velocity ratio, as heretofore defined.

The shutters are urged against the matrix contact faces by stationary hydraulic loading cylinders 30, 30*a*, which contain pistons 31, 31*a*, connected to the shutter shafts. A suitable pressure fluid, e. g., oil, is admitted into the cylinders by branch conduits 32, 32*a*, both of which are in communication with a pressure regulating valve 33 and with a source of fluid under pressure, such as a reservoir, indicated schematically at 34, and a pump 35. A return conduit 36 permits fluid to be vented to the reservoir. The cylinders and pistons thus constitute variable pressure devices for applying to the shutters pressures that are controlled by the regulating valve 33 which is, in turn, actuated by a sensing device.

The means for sensing the induced velocity ratio comprises a differential gear unit 37 illustrated in Figures 1 and 3. This unit is supported on stationary bearings 38 by means of its rotatable input shafts 39 and 47. Input shaft 39 is coupled to the shutter shaft 25*a* by means of sprockets 40 and 41 and a sprocket chain 42. The gear unit comprises a casing 43 which is rotatable about the shaft 39 and has tubular extension 43*a* extending over a part of this shaft. For assembly the casing may be made of two sections, as shown. The casing constitutes the planet carrier and supports the shafts 44 and 44*a* of planet gears 45 and 45*a*, and houses a sun wheel 46 which is mounted fast on a shaft 47, is rotatable therewith within the casing, and meshes with the gears 45, 45*a*. Also rotatable within the casing is an internally toothed gear 48 meshing with the planet gears and fast on the shaft 39. The shaft 47 forms the second input shaft to the differential gear unit and is coupled to the matrix drum 10 by means of a pinion 49 meshing with the gear rack 17 and contained within an enlargement 12*a* of the casing. It is evident that the internally toothed gear wheel 48 is driven in one direction at a velocity proportional to that of the shutters 20 while the sun wheel 46 is driven in the opposite direction at a velocity proportional to that of the matrix drum, and that the casing 43 will remain stationary at a predetermined ratio of these velocities, which is determined by the gear ratios of the coupling devices. When the induced velocity ratio varies from the said predetermined value the casing 43 is caused to rotate in a direction dependent upon the direction of the deviation. This rotation produces a torque for controlling the regulating valve 33.

Referring to Figures 3 and 4, a lever 50 is integral with the sleeve 51 which is rotatably mounted on the casing 43; it bears frictionally against a shoulder of the casing at one end of the sleeve and against a spring 52 at the other end thereof. The spring is retained by a nut 53 threaded to a tubular extension 43*a* of the casing. The spring 52 is loaded sufficiently to secure the transmission of torque from the casing 43 to the lever 50 when the former rotates while permitting slippage. This torque may be in a clockwise or counter-clockwise direction and may vary from zero upwards according as the induced velocity ratio is greater than or less than the said predetermined value. The lever 50 is linked by a pivoted connecting rod 54 to a combined cam and lever 55 which is pivoted at 56 and operates the pressure regulating valve 33 which may be of a known type.

The balanced pressure regulating and relief valve illustrated in Figure 5 comprises a housing 57 having a longitudinal bore providing a pressure inlet passage 58 for connection to the pump 35 and a passage 59 for connection to the branched conduits 32 and 32*a*, the passages 58 and 59 being always in communication. The housing has a vertical bore intersecting the former and providing an exhaust passage 60 for connection to

the return conduit 36 and a chamber 61 within which the exhaust valve member 62 is slidably mounted. The top of this bore is closed by a head 63 having a bore 64 for receiving the reduced, upper part of the valve member 62. The valve member is formed as a piston, the under side of which is equal in area to the upper side. The two sides of the piston are interconnected by an orifice 65, and the upper side is in communication with the exhaust passage 60 via a bore 65*a* in the head controlled by a pilot ball valve 66 and a bore 67 extending through the valve member. A light spring 68 holds the exhaust valve member on its seat 69 and this valve will remain closed by the action of the spring as long as the pilot valve 66 is closed, the fluid pressure being equal on both sides of the piston. If the pressure in the control pressure passages 58 and 59 rises above the pilot valve seating, the latter will open and permit oil to by-pass to the exhaust passage 60. This will create a differential pressure across the piston, due to a pressure drop in the orifice 65 and cause the piston and exhaust valve to rise and thus release oil to the return conduit 36, thereby partly venting the cylinders 30 and 30*a*. When the pressure falls the valve 66 closes and the spring 68 closes the valve member 62. The pressure in the passage 59 is therefore dependent on the loading of the pilot ball valve 66. This loading is controlled by varying the amount of compression on a spring 70 via a piston 71 connected to a cam follower 72 in engagement with the cam 55. It will be understood that the valve 62 does not extend fully across the longitudinal bore in the housing 63 and therefore permits full communication between passages 58 and 59 in all positions thereof. The pump 35 is operated at a low pumping rate and oil is continually supplied to the passage 58.

In operation the positively driven shutter rings 20 induce rotation of the matrix drum 10 through friction of their sealing faces. The shutter shaft 25*a* thereupon drives the input shaft 39 and the internally toothed gear wheel 48 while the frictionally-induced rotation of the drum is transmitted to the sun wheel 46 via the spur gear 49. The gear wheel sizes are so chosen in diameter in relation to each other as to secure the result that when the induced velocity ratio is about equal to the critical value above which leakage across the mating surfaces of the shutters and end contact faces of the matrix drum tends to increase, there is no torque transmitted to the planet carrier casing 43 and, hence, to the lever 50. When, however, this induced velocity ratio increases (indicating too much slippage between the shutter and drum), a torque is induced to the lever 50 which thereupon actuates the cam 55 to shift the piston 71 to the right and thereby increases the loading of the spring 70 on the pilot ball valve 66. This increases the fluid pressure in the cylinders 30 and 30*a* and thereby increases the axial thrust which is applied to the shafts 25 and 25*a* and increases the hydraulic loading on the shutters, whereby the induced velocity ratio is restored to the desired value and leakage of heat-exchanging fluid is minimized or eliminated. If the induced velocity ratio should fall below the said critical value, a torque in the opposite direction is induced to the lever 50 and the hydraulic servo-mechanism is actuated in the opposite sense to reduce the hydraulic loading on the shutters so as to increase the said induced velocity ratio.

It will be evident that the arrangement described above by reference to Figures 1 to 5 could equally well apply to the case in which the matrix drum 10 is positively driven and induces rotation to the shutters 20 by friction. Such a modification is indicated in Figure 8 wherein the shaft 47*a*, now larger than the shaft 47 of Figure 1, carries a sprocket 73 meshing with a sprocket chain 74, the latter being driven by any suitable power device. The shaft 47*a* thereby rotates the matrix drum 10 through the pinion 49 and annular gear rack 17. The parts 26 to 29, inclusive, of Figure 1 would, of course, be omitted in this embodiment.

Referring to Figures 6 and 7 there is shown an alternative arrangement for driving the differential gear unit off the periphery of the matrix drum involving a friction roller. In this embodiment, the input shaft 47 of the differential gear unit is bearingly supported in a gear casing 75 which is fixed to the casing 12 outside of the periphery of the matrix drum and carries fixed thereto a gear wheel 76 situated between the parallel, spaced parts of a pivoted follower arm 77 which also carries gear wheels 78 and 79. Mounted on the shaft carrying the gear wheel 79 is a friction roller 80 which is urged into contact with the periphery of the matrix drum 10 through a spring 81 housed within a well 82 of the casing 75 and pressing against the follower arm 77 through an axially movable abutment pin 83. The follower arm is rotatable about the shaft 47. Thereby rotation of the drum 10 is transmitted via the friction roller 80, gear wheels 79, 78 and 77 to the shaft 47 and to the sun wheel 46 mounted thereon. The pivotal support of the follower arm 77 about the shaft 47 permits rocking of the arm around the shaft in sympathy with any irregularities in the peripheral surface of the matrix drum.

As was indicated above, the invention is not limited to the use of hydraulic devices for loading the shutters and other arrangements, such as spring-loaded devices, may be used. Such an arrangement is illustrated in Figure 9, wherein like reference numbers indicate parts previously described. The rotatable and axially movable shafts 25 and 25*a* carry thrust collars 84 forming rotatable abutments for coiled springs 85 that bear against the rotatable races of thrust bearings having their non-rotatable races mounted within sleeves 86. These sleeves are rigidly connected to arms 87, 87*a* that are in turn rigidly connected to coaxial rods 88 and 88*a*, respectively, which are axially slidable in stationary supports 89. The parts of the rods engaged by the supports have flattened sides, as shown, whereby the rods are secured against rotation. The near ends of the rods are internally threaded with left- and right-hand threads, respectively, and receive a stud 90, the ends of which are correspondingly threaded. The stud carries a sprocket 91 which is connected by a sprocket chain 92 to a sprocket 93 fixed on the sleeve 51 (see Figure 3) of the differential gear unit. This latter sprocket thus replaces the lever 50 of the previous embodiment and rotation of the casing 43 of the differential gear imparts a torque to the sprocket 93.

It is evident that when the induced velocity ratio rises the differential gear unit 37 imparts a torque to the sprocket 93 to rotate the stud 90 in a direction pulling the rods 88 and 88*a* closer together. This translatory motion is transmitted to the sleeves 86 whereby the springs 85 are compressed and an increased axial force is imposed on the shafts 25 and 25*a* to increase the loading on the shutters and reduce the induced velocity ratio. Since the assembly of the two rods 88, 88*a* and the stud 90 is free to shift as a unit, it assumes a position determined by the springs 85 such that these springs are equally loaded. The pressures of the shutters 20 on the opposite end contact faces of the matrix drum will, therefore, be substantially equal regardless of the angular position of the stud 90. A variation in the induced velocity ratio in the downward direction similarly results in a torque being applied to the sprocket 93 but in the opposite direction, whereby the spring tensions are reduced and the loading on the shutters is reduced.

In the special case where the matrix drum is stationary and all that is needed is a control of the relation between the velocity of rotation of the shutter axis about the axis of the drum to the angular velocity of the shutters themselves with respect to the drum, it will be evident that the arrangement for controlling the pressure between the shutter and the respective matrix drum contact faces with a view to maintaining the induced velocity ratio within the desired limits will undergo some modification over that described above. One such arrangement is shown in Figure 10 by way of illustration. This view shows a portion of the heat exchanger according to Figure 8 of the aforesaid U. S. patent, wherein the matrix drum is stationary and comprises concentric outer and inner cylindrical shells 110 and 110*a*, the latter enclosing an inner dead space and the annular space between these shells containing the matrix ducts 111 which terminate in annular, plane contact faces; only one of these faces appears in the drawing, it being understood that the opposite face is similarly arranged. A stationary outer duct 112 for the flow of one heat-exchanging fluid is fixed to each end of the shell 110, shaped so that the ends remote to the matrix drum curve away from the central axis of the drum. An inner duct 113 for the flow of the other heat-exchanging medium, e. g., the one at the higher pressure, is mounted coaxially with the axis of the shell 110 and within each outer conduit 112, terminating some

distance from the contact face of the matrix drum. A rotatable, crank-like duct **114** is fitted to each inner conduit **113** and rotatably sealed thereto by means of sealing flanges **115, 116.** The inner ends of each duct **114** extend laterally outwardly from the central axis of the drum and terminate in close proximity to the drum, the ports thereof being substantially internally tangent to the shell **110** and externally tangent to the shell **110***a*. Each inner end has an annular ring **117** with an external row of gear teeth **118** which mesh with a spur gear **119.** By turning the spur gear **119** the ring **117** and duct **114** may be rotated about the central axis of the matrix drum, it being understood that the two ducts at the opposite ends of the drum are moved in synchronism. The port of the duct **114** is enlarged near the matrix drum and contains a ring-shaped shutter **120** which has limited axial movement and is rotatable within the port, being externally in fluid-tight relation to the port and having an annular sealing face in rubbing contact with the matrix contact face. The shutter has radial spokes **121** extending to a central hub **122** to which a shutter shaft **125** is connected loosely to permit the shutter to rock or tilt with respect to the shaft axis, but to transmit torque and axial thrust. The shutter shaft **125** is guided in a framework comprising radial spokes **123** fixed to the duct **114** and a central sleeve **124.**

Considering now the aspects of this embodiment affected by the instant invention, the duct **114** carries a differential gear unit **126** which is supported by its two input shafts **127** and **128** (which correspond to the shafts **39** and **47**, respectively, in Figure 3). Shaft **127** is fast on the inner shell, and the ring **117** and duct **114** are rotatable about this shaft, whereby it serves to center the duct with respect to the matrix drum. A fluid-tight running seal is provided at **129.** The shaft **128** is rotatably mounted on an open spider **130** carried by the duct **114**; it is rotated at angular velocity proportional to the angular velocity of the shutter **120** through spur gears **131** and **132,** shaft **133,** sprocket **134,** sprocket chain **135** and sprocket **136,** the last being fast on the shutter shaft **125.** The shaft **133** that carries the gear **132** and sprocket **134** is rotatably mounted in the spider **130** and in a bracket **137** projecting from the duct **114.** The shutter shaft **125** terminates within a sleeve **138** and has axial and rotary motion relative thereto, but is guided thereby to position the axis of the shutter shaft. Axial thrust is transmitted from the sleeve to the shaft by a thrust bearing **139** carried by the sleeve and a spring **140** acting between the rotatable race of the bearing and a collar on the shutter shaft. The sleeve **138** is internally threaded and receives a threaded stud **141** that is stationary with respect to the duct **114,** whereby rotation of the sleeve moves the thrust bearing toward or away from the shutter to vary the loading on the spring **140** and the shutter. The sleeve **138** has a peripheral sprocket **142** fixed thereto, connected by a sprocket chain **143** to a sprocket **144** which is in frictional engagement with the housing of the differential gear unit, replacing the lever **50** of Figure 3.

When the embodiment of Figure 10 is in operation, power is applied to the spur gear **119,** thereby rotating the ring **117** and the rotatable duct **114** at a positively-induced angular velocity about the stationary matrix drum **110** and the stationary shaft **127.** Frictional forces cause the shutter **120** to rotate at a frictionally-induced angular velocity. Considered in relation to the duct **114,** the input shafts **127** and **128** of the differential gear unit **126** are turned in opposite directions and at velocities proportional to the positively-induced and frictionally-induced velocities, respectively, the proportionality being dependent upon the relative sizes of the gears **131** and **132** and the sprockets **134** and **136,** which are selected to cause the casing of the differential gear unit to remain stationary with respect to the duct **114** when the induced velocity ratio is at a desired, predetermined value, preferably close to the aforesaid critical value. Should the angular velocity of the shutter **120** be too low, indicating too high an induced velocity ratio, the casing of the differential gear unit rotates to place a torque on the sprocket **144** which rotates to turn the sleeve **138** on the threaded stud **141;** this increases the loading on the spring **140** and, hence, on the shutter **120,** thereby lowering the induced velocity ratio. Conversely, when the shutter is pressed against the matrix drum too tightly the induced velocity ratio is too low, and the differential gear casing causes the sleeve **138** to rotate in the opposite direction, thereby decreasing the loading and increasing the induced velocity ratio.

I claim as my invention:

1. A regenerative heat exchanger comprising three members of which one is a heat accumulating matrix having separate matrix ducts terminating in an end contact face, the second is a shutter support situated opposite to and eccentric to said contact face and the third is a shutter mounted on said support and having a peripheral sealing face in sealing and rubbing engagement with said contact face over a minor, eccentric portion of the area of the contact face and having further a flow opening within said peripheral sealing face, said support and matrix being relatively rotatable for causing the shutter to sweep the contact face with a sweeping rotary movement about the center of the contact face and said shutter being mounted to have a rotary movement relative to the matrix separate from said sweeping movement about an axis that is eccentric to the center of the contact face; first and second conduits disposed for the flow of different heat exchange media, one of said conduits being in flow communication with said flow opening in the shutter and the other being in flow communication with the termini of matrix ducts that lie outside of said shutter; means for positively rotating one of said three members to induce positively one of said rotary movements, thereby inducing the other of said rotary movements by friction between said contact face and the sealing face; means for applying a pressure between said shutter and the contact face of the matrix; and means for varying the said pressure during the said rotary movements.

2. A regenerative heat exchanger according to claim 1 wherein said means for positively rotating one of the three members comprises a drive shaft connected to the shutter ring for positively rotating the shutter ring.

3. A regenerative heat exchanger according to claim 1 wherein said matrix is a rotatable drum and the means for positively rotating one of the three members comprises a drive pinion cooperating with the matrix drum for positively rotating the matrix drum.

4. A regenerative heat exchanger having a heat accumulating matrix drum with a plurality of separate, longitudinal matrix ducts terminating in end contact faces; a first pair of conduits for the flow of a first heat exchanging medium situated at opposite ends of the drum and having ports adjacent said faces and eccentric thereto; a shutter for each of said ports, each shutter having a peripheral sealing face in sealing and rubbing engagement with the respective contact face and surrounding a minor, eccentric portion of the area of said contact face, said shutter having a flow opening inside of the peripheral sealing face communicating with the respective first conduit and being mounted for rotation relative to the drum and relative to the first conduits about an axis eccentric to the central axis of the drum; a shutter support for each shutter mounted for relative sweeping movement of the supported shutters over the matrix contact faces; means for effective positive movement of one of said relatively movable elements, thereby inducing the other of said movements; second conduit means at opposite ends of said drum communicating with the termini of matrix ducts that lie outside of the shutters for the flow of a second heat exchanging medium; means for applying a pressure between the shutters and the said contact faces; and means for varying said pressure during said movements.

5. A regenerative heat exchanger comprising three members of which one is a heat accumulating matrix having separate matrix ducts terminating in an end contact face, the second is a shutter support situated opposite to and eccentric to said contact face and the third is a shutter mounted on said support and having a peripheral sealing face in sealing and rubbing engagement with said contact face over a minor, eccentric portion of the area of the contact face and having further a flow opening within said peripheral sealing face, said support and matrix being relatively rotatable for causing the shutter to sweep the contact face with a sweeping rotary movement about the center of the contact face and said shutter being mounted to have a rotary movement relative to the matrix separate from said sweeping movement about an axis that is eccentric to the center of the contact face; first and second conduits disposed for the flow of different heat exchange media, one of said conduits being in flow communication with said flow opening in the shutter and the other being in flow communication with the

termini of matrix ducts that lie outside of said shutter; means for positively rotating one of said three members to induce positively one of said rotary movements, thereby inducing the other of said rotary movements by friction between said contact face and the sealing face; a sensing device for sensing the relation between the velocities of said rotary movements; and a variable pressure device responsive to said sensing device for applying an increased pressure between said shutter and the contact face of the matrix when the velocity of the positively induced rotary movement increases in relation to the velocity of the frictionally induced rotary movement.

6. A regenerative heat exchanger according to claim 5 wherein said sensing device comprises a differential speed device having one input connected to move in accordance with the said rotary movement of the shutter about the eccentric axis and a second input connected to move in accordance with the rotary sweep movement and having the output thereof connected to control said variable pressure device.

7. A regenerative heat exchanger according to claim 6 wherein the variable pressure device comprises a servomechanism operating in response to the said output of the differential speed device to increase the said pressure.

8. A regenerative heat exchanger according to claim 5 wherein said matrix is rotatable to effect said sweeping movement; said sensing device comprises a differential gear unit of which one input is drivingly connected to the rotating shutter and another input is drivingly connected to the matrix; and the variable pressure device comprises a hydraulic piston and cylinder combination arranged to apply a loading on the shutter when hydraulic fluid under pressure is admitted to the cylinder, a source of hydraulic fluid under pressure, and a pressure regulating valve connected between the said source and the cylinder, said valve being connected to be controlled by the output of said differential gear unit.

9. A regenerative heat exchanger according to claim 5 wherein the shutter support comprises a rotatable and axially movable shaft connected in axial thrust- and torque-transmitting relation to the shutter and the variable pressure device is connected to said shaft for imparting axial thrust thereto.

10. A regenerative heat exchanger according to claim 9 wherein the said means for positively rotating one of the three members comprises drive means acting on said shaft for rotating the shaft and shutter.

11. A regenerative heat exchanger according to claim 9 wherein the matrix is rotatable and the said means for positively rotating one of the three members comprises a drive pinion cooperating with said matrix for positively rotating the matrix.

12. A regenerative heat exchanger according to claim 5 wherein the matrix is rotatable and the sensing device has one input thereof drivingly connected to the matrix by a friction wheel in engagement with the periphery of the matrix.

13. A regenerative heat exchanger according to claim 5 wherein the matrix is stationary and the shutter support is mounted for rotation about the center of the matrix contact face; the said means for positively rotating one of the three members comprises drive means acting on the shutter support to effect the said sweeping rotary movement, whereby rotation of the shutter on the shutter support about the eccentric axis thereof is induced by friction.

14. A regenerative heat exchanger according to claim 13 wherein the sensing device comprises a differential gear unit mounted for rotation bodily with the said shutter support, one input of said gear unit being drivingly connected to a stationary part of the heat exchanger and another input thereof being drivingly connected to the shutter supported by the shutter support.

15. A regenerative heat exchanger having a heat accumulating matrix drum with a plurality of separate, longitudinal matrix ducts terminating in end contact faces; a first pair of conduits for the flow of a first heat exchanging medium situated at opposite ends of the drum and having ports situated adjacent said faces and eccentric to the central axis of the drum, a ring-shaped shutter at each port communicating therewith and adapted for motion in a direction parallel to said central axis of the drum, said shutter having a peripheral sealing face in sealing and rubbing engagement with the respective contact face and surrounding a minor, eccentric portion of the area of said contact face, said drum and port being relatively rotatable about the central axis of the matrix drum to cause said shutters to sweep said end contact faces with a rotary sweeping movement, said shutters being rotatable with respect to the said conduits for rotary movements about axes eccentric to said central axis of the drum separate from said sweeping movement; second conduits at opposite ends of said drum communicating with the termini of matrix ducts that lie outside of the shutters for the flow of a second heat exchanging medium; drive means for positively inducing one of said rotary movements, whereby the other of said rotary movements is induced by friction between said contact faces and said shutters; a differential speed sensing unit connected to sense the induced velocity ratio; a variable pressure device for applying a variable pressure on the shutters urging them against the contact faces of the drum; and control means for the variable pressure device responsive to the output of the differential speed sensing unit for increasing the pressure when the induced velocity ratio rises above a predetermined value and for decreasing the said pressure when the induced velocity ratio falls below said predetermined value.

16. A regenerative heat exchanger of the kind specified having a heat accumulating matrix drum with a plurality of separate, longitudinal matrix ducts terminating in end contact faces and mounted for rotation about the central axis thereof; first conduits for the flow of one heat exchanging medium situated at opposite ends of the drum and having stationary ports adjacent said faces, said ports covering minor portions of said end faces and being eccentric to said central axis; a ring-shaped shutter at each of said ports mounted in sealing relation thereto and being rotatable about an axis eccentric to said central axis, each shutter having a sealing face disposed in sealing and rubbing engagement with the respective end contact face; a pair of second conduits for the flow of a second heat exchanging medium, one conduit being connected to each face of the drum for communication with the termini of matrix ducts lying outside of said shutters; and a shaft for at least one of said shutters connected in torque-transmitting relation to the shutter and extending rotatively through a wall of a first conduit for rotation with said shutter.

17. A regenerative heat exchanger according to claim 16 wherein said shaft is connected also in axial thrust-transmitting relation to said shutter and the shutter is mounted for axial movement toward and from said matrix drum, said shaft having connected thereto a variable pressure device for applying an axial thrust to the shaft in a direction toward the matrix drum.

18. In combination with the heat exchanger according to claim 17, means for positively rotating one of said rotatable members; means for sensing the induced velocity ratio; and control means responsive to the sensed induced velocity ratio for increasing said thrust applied to the shaft as the sensed induced velocity ratio increases.

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