United States Patent

Benaroya

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[54] TANDEM FREE-PISTON MACHINES

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[52] **U.S. Cl.** **417/341,** 123/46

[51] **Int. Cl.** **F04b 17/00,** F04b 35/00, F02b 71/00

[58] **Field of Search** ..... 417/11, 34 D, 341, 343, 364; 123/46

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[57] **ABSTRACT**

A tandem free-piston machine has two movable trains comprising drive and compressor pistons. Synchronizing means are provided between these trains and include an elastic member to absorb at least partly any momentary difference in the forces to which the movable trains are subjected. The synchronizing means may be rack and pinion, or lever and connecting rod means. The elastic member may be a torsionally elastic shaft connecting two pinions, or a bendable elastic bar constituting one of said levers.

8 Claims, 5 Drawing Figures

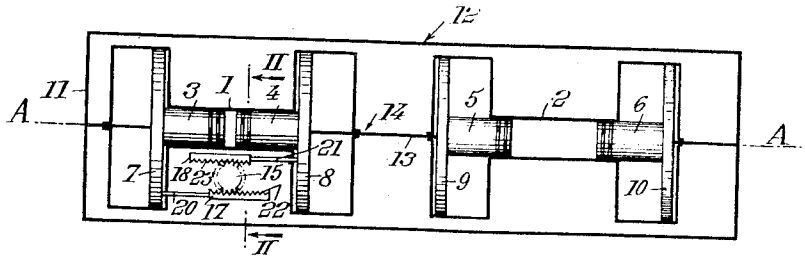

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Fig. 1.

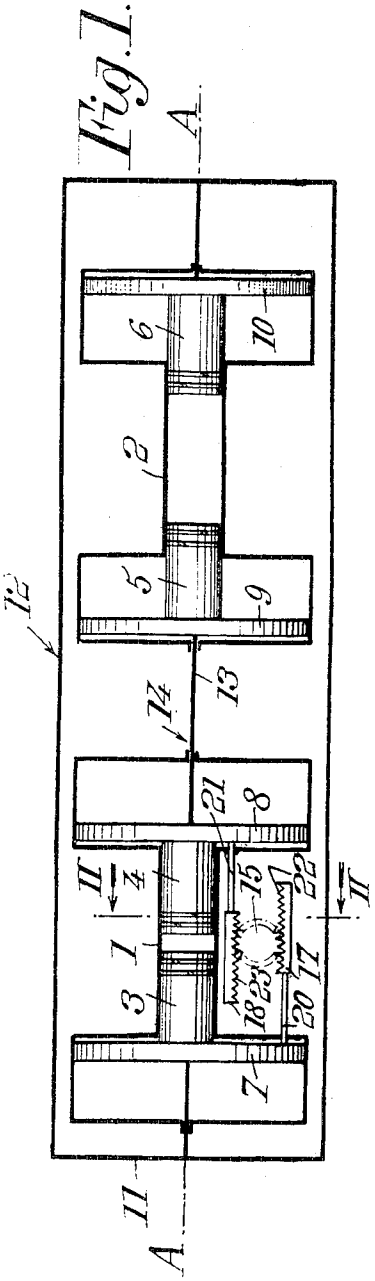


Fig. 4.

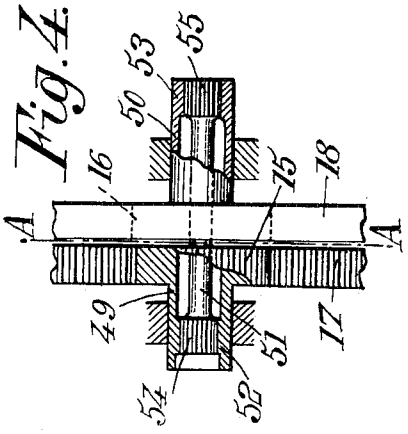
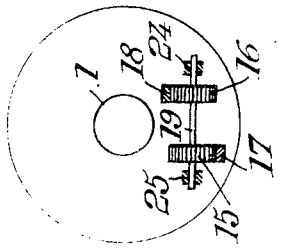


Fig. 2.



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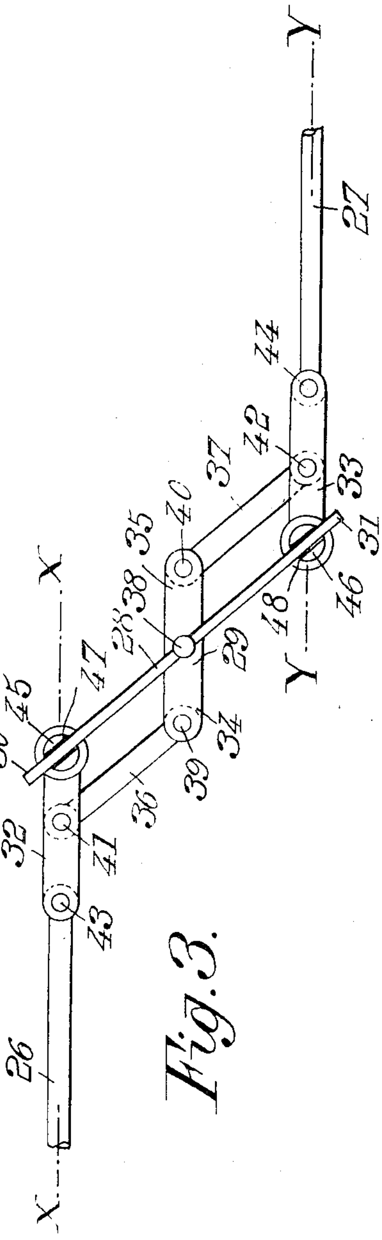
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Fig.3.

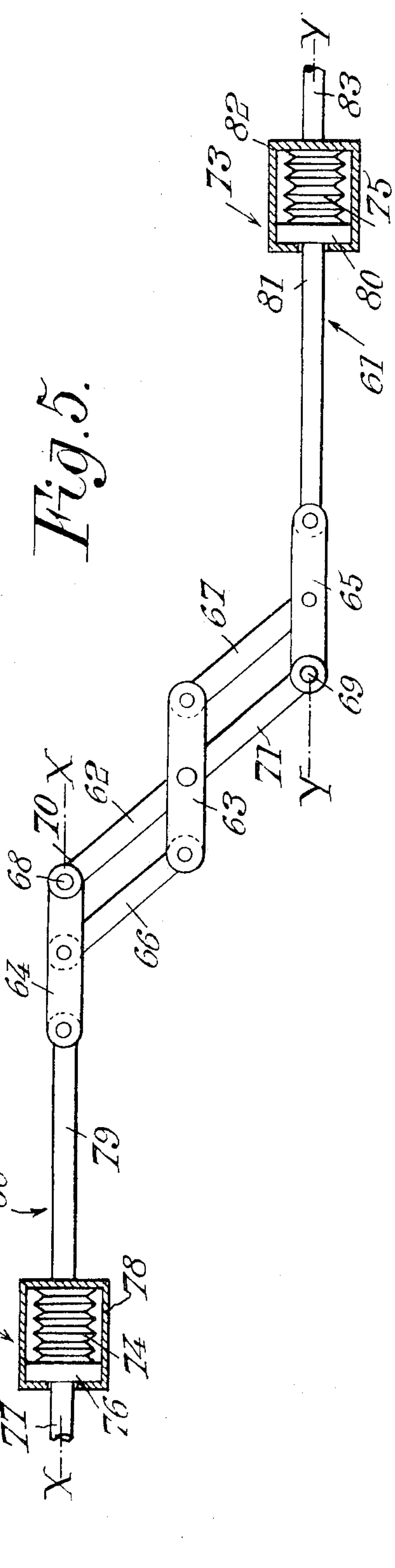
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Fig.5.

TANDEM FREE-PISTON MACHINES

The invention relates to tandem free-piston machines of the type comprising at least one group of two drive cylinders which are aligned and in each of which two drive pistons work in opposition driving respective compressor pistons, the drive pistons nearest to the ends of the group (called hereinafter outer drive pistons) and the corresponding compressor piston or pistons being rigidly connected to constitute a first movable train, the other drive pistons (hereinafter called inner drive pistons) and the corresponding compressor piston or pistons being also rigidly connected to constitute a second movable train, synchronizing means being provided between the two movable trains which move in opposite directions on each cycle of the machine.

These synchronizing means are in general constituted by light members adapted to transmit only small forces since they are only provided to compensate for the accidental slight differences which come into play between the resistances which oppose the movements of the movable trains.

In known tandem free-piston machines, comprising for example one group of two aligned drive cylinders, one of the drive pistons of each movable train is subjected, at the beginning of each cycle, to a combustion taking place in one or other of the drive cylinders and the forces thus furnished simultaneously to a drive piston of the first train and to a drive piston of the second train are transmitted respectively to compressor pistons which each of these trains include, that is to say, for each train, for example with a compressor piston associated with the drive piston subjected to the combustion and to a compressor piston associated with the other drive piston of the train.

The inventor has noted that, in the second movable train, the transmission of force from the inner drive piston subjected to the combustion to the other inner drive piston associated with a compressor piston is more rapid than the transmission of this same force, in the first movable train, between the outer drive piston subjected to the combustion and the other outer drive piston associated with a compressor piston, which is explained by the fact that the distance that the force between the outer drive pistons must traverse is greater than the distance that the force between the inner drive pistons must traverse.

Therefore, when the force supplied to an inner drive piston arrives at the compressor piston associated to the other inner drive piston (this compressor piston then providing work of compression) this same force furnished to an outer drive piston has not yet arrived at the compressor piston associated with the other outer drive piston (this compressor piston not yet furnishing work of compression). This situation, which appears at each cycle, only lasts a very short instant until all the forces are transmitted; but during this short instant, the two movable trains are not subjected to the same forces and the difference between these forces must be compensated by said synchronizing means. These synchronizing means are not designed to transmit this difference between the forces which can reach a considerable magnitude and they are thus rapidly rendered unserviceable.

It is an object of the invention, particularly, to overcome the above-mentioned drawback and to render tandem free-piston machine of the type concerned such that they respond better than those up to the present to the various desiderata of practice.

It consists, principally, in tandem free-piston machines of the type concerned, in including with the synchronizing means at least one elastic member adapted to absorb, at least partly, a momentary difference between the forces to which each of the moving trains are subjected.

It consists, apart from this principal feature certain other features which are used preferably at the same time and of which a more explicit description will be given below.

The invention, in any case, will be well understood with the aid of the additional description which follows, as well as with the accompanying drawings, which supplement and which drawings are of course, given mainly by way of indication.

FIG. 1 of these drawings shows, in plan and diagrammatically, one embodiment of a tandem free-piston machine constructed according to the invention.

FIG. 2 shows, in section along the line II—II of FIG. 1, the tandem machine of FIG. 1.

FIG. 3 shows, in plan view, a variation of synchronizing means which can be substituted in the tandem machine illustrated in FIGS. 1 and 2.

FIG. 4 shows, in elevation with portions removed, another variation of the synchronizing means shown in FIGS. 1 and 2.

FIG. 5, finally, shows a variation of the synchronizing means of FIG. 3.

As regards first of all the tandem free-piston machine as a whole, it is made to include two aligned drive cylinders 1 and 2, in each of which two drive pistons work in opposition (denoted by 3 and 4 for cylinder 1 and by 5 and 6 for cylinder 2) driving compressor pistons 7, 8, 9 and 10 respectively.

The two outer drive pistons 3 and 6 nearest to the ends of the machine and the corresponding compressor pistons 7 and 10 are rigidly fixed together by a connecting device 11 to constitute a first moving train 12. The two other inner drive pistons 4 and 5 and corresponding compressor pistons 8 and 9 are rigidly fixed together through a rod 13 to constitute a second moving train 14. The tandem machine is shown schematically in FIG. 1 and includes neither apertures, nor valves nor ignition devices which play no part in the comprehension of the invention.

As regards now the synchronizing means of the two moving trains 12 and 14, they can be effected by numerous constructions intended to synchronize, for example, the movements of pistons 7 and 8, or those of pistons 7 and 9, or again the movements of the rod 13 and of the connecting device 11.

Known synchronizing means include, for example, a pinion rotated by racks connected respectively to two movable trains, this pinion ensuring the synchronism of the movements of the two racks and, consequently, the synchronism of the movements of the two moving trains; these synchronizing means being able, according to another construction, to include a linkage and rigid lever system and hinged which connect the moving trains between themselves.

The synchronizing means provided according to these known constructions have, as has already been explained, to transmit on each cycle of the machine considerable momentary forces which cause them to deteriorate.

To overcome this drawback and according to the invention, there is included with the synchronizing means at least one elastic member adapted to absorb, at least partly, a momentary difference between the forces to which each of the moving trains 12 and 14 are subjected.

In the embodiment of the invention illustrated in FIGS. 1 and 2, there is advantageously included with the synchronizing means two identical pinions 15 and 16 which are coaxial and which are rotated respectively in the same direction by racks 17 and 18 connected respectively to the first moving train 12 and to the second moving train 14 and these two pinions 15 and 16 are connected along their axis of rotation by an elastic shaft 19 adapted to undergo torsion when the couples communicated by 17 and 18 to pinions 15 and 16 differ momentarily.

Rack 17, which is fixed for example to the compressor piston 7 through a rod 20, displaces parallel to the axis A—A along which are effected the movements of the pistons of the moving trains and which is the same for the rack 18 which is fixed, for example, to the compressor piston 8 through a rod 21.

Racks 17 and 18 are advantageously arranged, as shown in FIG. 2, on both sides of the plane of FIG. 1 (passing through the axis A—A), so that pinions 15 and 16 can be connected by a torsion shaft 19 of sufficient length and the surface 22 of the rack 17 meshing with the pinion 15 is turned towards the top of the machine shown in FIG. 1 while the surface 23 of the rack 18 engaging with the pinion 16 is turned towards the base of the machine of FIG. 1.

The elastic shaft 19 is carried, for example, by bearings 24 and 25 fixed with respect to the drive cylinder 1.

When the forces to which the two mobile trains 12 and 14 are subjected differ momentarily (for example when the compressor piston 9 of the second train 14 commences to accomplish a work of compression although, as a result of the length of the stroke of the force in the rods of the connecting device 11, the compressor piston 10 of the first moving train 12 has not yet commenced to accomplish a work of compression), the elastic shaft 19 towards which this momentary difference between the forces is applied undergoes an elastic torsion absorbing, at least in part, the difference while, in known synchronizing means, this difference between the forces is transmitted integrally from one moving train to the other through racks of which the teeth are deformed and wear.

The variation of the synchronizing means, which takes the place of the assembly 15–23 of FIG. 1, is shown in FIG. 3. It is similarly coupled to the mobile trains 12 and 14 along a direction parallel to the axes X—X and Y—Y. These moving trains 12 and 14 of FIG. 1, have not been shown in FIG. 3, but only rods 26 and 27 which are assumed to be fixed respectively to the moving trains 12 and 14, so that they are displaced along the axes X—X and Y—Y.

There is advantageously included with the synchronizing means a first lever 28 constituted by an elastic bar and a second lever 29 which are pivoted at their centers, the first lever 28 being connected by its ends 30 and 31 to rods 26 and 27 through the tie-and-push-rods 32 and 33 similar and parallel to the second lever 29 and the second lever 29 being connected by its ends 34 and 35 to tie-and-push-rods 32 and 33 through link-rods 36 and 37 similar and parallel to the first lever 28, the elastic bar which forms the first lever 28 being hinged to rods 32 and 33 so that, when the forces communicated to the rods 26 and 27 by the moving trains 12 and 14 differ momentarily, it can undergo a flexion absorbing, at least partly, this difference.

The levers 28 and 29 are advantageously pivoted by a common pivot 38, the second lever 29 bears pivots 39 and 40 on which are hinged the link-rods 36 and 37 and the tie-and-push-rods 32 and 33 bear pivots 41 and 42 respectively on which are hinged the link-rods 36 and 37 and pivots 43 and 44 on which are hinged the rods 26 and 27.

In addition, the tie-and-push-rods 32 and 33 bear crankpins 45 and 46 provided with holes 47 and 48 in which slide the ends 30 and 31 of the first lever 28 constituted by an elastic bar. It is noted that, when the elastic bar 28 undergoes flexion, the ends 30 and 31 of this bar then slide freely in the holes 47 and 48 conforming to the geometrical properties of the levers, tie-and-push-rods and link-rods arranged as has just been described.

In the example of FIG. 3, it is the lever 28 which is constituted by an elastic bar, but there could also be a lever 29 formed by an elastic bar, the pivots 39 and 40 then being replaced by crankpins analogous to the crankpins 45 and 46.

On the operation of the tandem machine, the rods 26 and 27 are displaced in reverse directions at each cycle of the machine along the axes X—X and Y—Y, and the parallelograms constituted by the levers 28 and 29, the tie-and-push-rods 32 and 33 and the link-rods 36 and 37 are deformed, so that the pivots 43 and 44 are displaced along the axes X—X and Y—Y, the pivot 38 remaining in position.

If, during a reduced interval of time, a force to which the second train is subjected (to which the rod 26 is fixed for example) is less than the force to which the first train is subjected (to which the rod 27 is fixed for example), the difference between these forces is applied to the elastic bar 28 which undergoes a flexion absorbing this difference at least partly. With known synchronizing means including tie-rods, link-rods and rigid levers, this difference is transmitted wholly through these members from one moving train to the other, which subject these members to stresses much greater than those for which they are provided.

In a tandem machine, such as is shown in FIG. 1, it may be advantageous to arrange racks 17 and 18 on both sides of the plane of FIG. 1 (passing through the axis A—A) and in the immediate proximity of this plane, which was not the case in the embodiment shown in FIGS. 1 and 2.

As has been shown in FIG. 4, placing racks 17 and 18 in the immediate proximity of the vertical plane passing through the axis A—A (FIG. 1) of the machine and, consequently, coaxial pinions 15 and 16 in the immediate proximity of one another, there are provided two cylinders 49 and 50 coaxial with the pinions 15 and 16 and respectively fixed to the said pinions on both sides of the latter and an elastic shaft 51 is arranged so that it connects the ends 52 and 53 of the cylinders 49 and 50 by passing through the two cylinders and the pinions 15 and 16.

The elastic shaft 51 can, similarly to the shaft 19 of FIG. 2, undergo torsion when the torques applied to the pinions 15 and 16 and to the corresponding cylinders 49 and 50 are different.

The shaft 51 is advantageously connected to the ends 52 and 53 of the cylinders 49 and 50 by grooves arranged at the ends 54 and 55 of the shaft 51 and co-operating with grooves arranged in the cylinders 49 and 50, at their ends 52 and 53.

In another embodiment of the invention which is illustrated in FIG. 5, there are provided synchronizing means constituted by two rods 60 and 61, respectively fixed to two movable trains (not shown in FIG. 5) of a tandem machine such as assemblies 12 and 14 of FIG. 1, and by a system of levers 62 an 63, of tie-rods 64 and 65 and of link-rods 66 and 67 similar to that of FIG. 3, save for the fact that the lever 62 is no longer an elastic bar, but is rigid. All the components of the said system and the crankpins 45 and 46 of FIG. 3 are replaced by pivots 68 and 69 by which the link-rods 64 and 65 are respectively hinged to the ends 70 and 71 of the lever 62.

This being the case, there are inserted in rods 60 and 61 respectively, elastic elements 72 and 73 adapted to undergo compression along the axes X—X and Y—Y by displacements of the rods 60 and 61 when the forces communicated by the movable trains to the said rods differ momentarily.

Each of these elastic elements 72 (or 73) is advantageously constituted by a stack 74 (or 75) along the axis X—X (or along the axis Y—Y) of elastic washers such as for example Belleville washers, the stack 74 being arranged between a piston 76 rigidly fixed to the portion 77 of the rod 60 and a cylinder 78 which is rigidly fixed to the portion 79 of the rod 60 and in which the piston 76 can slide and the stack 75 being arranged between a piston 80 rigidly fixed to the portion 81 of the rod 61 and a cylinder 82 which is rigidly fixed to the portion 83 of the rod 61 and in which the piston 80 can slide. The portions 77 and 79 of the rod 60 are held aligned along the axis X—X by guides (not shown) and the portions 81 and 83 of the rod 61 are also held aligned along the axis Y—Y by guides (not shown).

When the mobile trains of the tandem machine are subjected during a short interval of time to different forces, the difference between these forces is exploited, at least partly, to compress the stack 74 or the stack 75 (by assuming that the greatest force is applied to the rod 60, it is the stack 74 which is compressed when this force is directed from left to right of the FIG. 5 and it is the stack 75 which is compressed when this force is directed from right to left of FIG. 5).

It is seen that the difference between these forces is not wholly transmitted from one mobile train to the other, which would be the case with synchronizing means similar to those of FIG. 5, without the elastic elements 72 and 73.

There could well also be provided conventional rack and pinion synchronizing means, the racks being connected respectively to the mobile trains by rods each having at least one portion parallel to the direction of displacement of the mobile train to which it is fixed and inserting in each of the above-said portions an elastic element adapted to undergo compression along the corresponding direction of displacement when the mobile trains are momentarily subjected to different forces.

Accordingly, whatever the embodiment adopted, there is obtained a tandem free-piston machine of which the operation

emerges sufficiently from the foregoing to render additional explanation unnecessary.

This tandem machine has numerous advantages of which the most important is that these synchronizing means which are provided to transmit only minimal forces between the mobile trains of the machine are protected by the elastic members against the considerable momentary differences between the forces to which said mobile trains are subjected at the beginning of each cycle of the machine.

In addition, synchronizing means provided according to the invention are simple and can be easily produced from known synchronizing means which are modified by including with them elastic members.

As is self-evident, and as emerges besides from what has already been described, the invention is not limited in any way to those of its embodiments, nor to those of its methods of construction of its various parts, which have been more particularly indicated; it embraces, on the other hand, all variations embodying the essential concept of the invention as defined in scope by the appended claims.

What I claim is :

1. A tandem, free piston machine comprising at least one group of two drive cylinders which are aligned and in each of which two drive pistons work in opposition driving respective compressor pistons, the drive pistons nearest to the ends of the group (hereinafter called outer drive pistons) and the corresponding compressor pistons being rigidly connected by first linking means to constitute a first mobile train, the other drive pistons (hereinafter called inner drive pistons) and the corresponding compressor piston or pistons being also rigidly connected by second linking means to constitute a second mobile train, said first linking means being longer than said second linking means, synchronizing means being provided between said two mobile trains which move in opposite directions on each cycle of the machine, said synchronizing means including elastic means adapted to absorb in both said opposite directions, at least partially, a momentary difference between the forces to which each of said mobile trains are subjected.

2. A tandem, free-piston machine according to claim 1, wherein said synchronizing means are lever and connecting rod means, one of said levers being constituted by an elastic member.

3. A tandem, free-piston machine according to claim 1, wherein the synchronizing means are connected respectively to the mobile trains by parts having each at least one portion parallel to the direction of the movement of the mobile train to which it is fixed, and each said portion includes an elastic element adapted to undergo compression when the forces communicated by the trains to the parts differ momentarily.

4. A tandem free piston machine according to claim 1, wherein said elastic means includes at least one elastic member, the elasticity of said elastic member being so selected that under the influence of abnormally high forces acting on the synchronizing device, especially when the free pistons are at their dead centers, said elastic member yields elastically for movements of said mobile trains in each of said opposite directions although it does not undergo any pronounced elastic deformation when normal forces act on the synchronizing device.

5. A tandem, free piston machine according to claim 4, wherein the synchronizing means comprises at least one lever with two arms rotatable around a fixed shaft, the ends of said lever being connected to elements belonging to the two trains moving in opposite directions, said lever being adapted to yield elastically only under the effect of forces exceeding those normally acting on the synchronizing device.

6. A tandem, free-piston machine comprising at least one group of two drive cylinders which are aligned and in each of which two drive pistons work in opposition driving respective compressor pistons, the drive pistons nearest to the ends of the group (hereinafter called outer drive pistons) and the corresponding compressor pistons being rigidly connected by first linking means to constitute a first mobile train, the other drive pistons (hereinafter called inner drive pistons) and the corresponding compressor piston or pistons being also rigidly connected by second linking means to constitute a second mobile train, said first linking means being longer than said second linking means, synchronizing means being provided between said two mobile trains which move in opposite directions on each cycle of the machine, said synchronizing means including elastic means adapted to absorb in both said opposite directions, at least partially, a momentary difference between the forces to which each of said mobile trains are subjected, wherein said synchronizing means are rack-and-pinion means comprising two racks and two pinions, each rack meshing with a separate said pinion, and said elastic means is an elastic rotary connection between said two pinions.

7. A tandem, free-piston machine according to claim 6, wherein said two pinions are coaxial and are connected along their axis of rotation by an elastic shaft adapted to undergo torsion when the torques communicated by each of the racks to the pinions have a momentary difference.

8. A tandem, free-piston machine according to claim 6, wherein the two pinions are coaxially disposed close to one another, and two cylinders coaxial with the said pinions are fixed respectively to and on both outer sides of the said pinions, the ends of said cylinders which are most separated from one another being connected by an elastic shaft passing through the two cylinders and the two pinions.

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