Nov. 10, 1970 R. R. TOEPEL 3,538,706

MULTICYLINDER HOT GAS ENGINE WITH POWER CONTROL

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Fig. 1

Fig. 2

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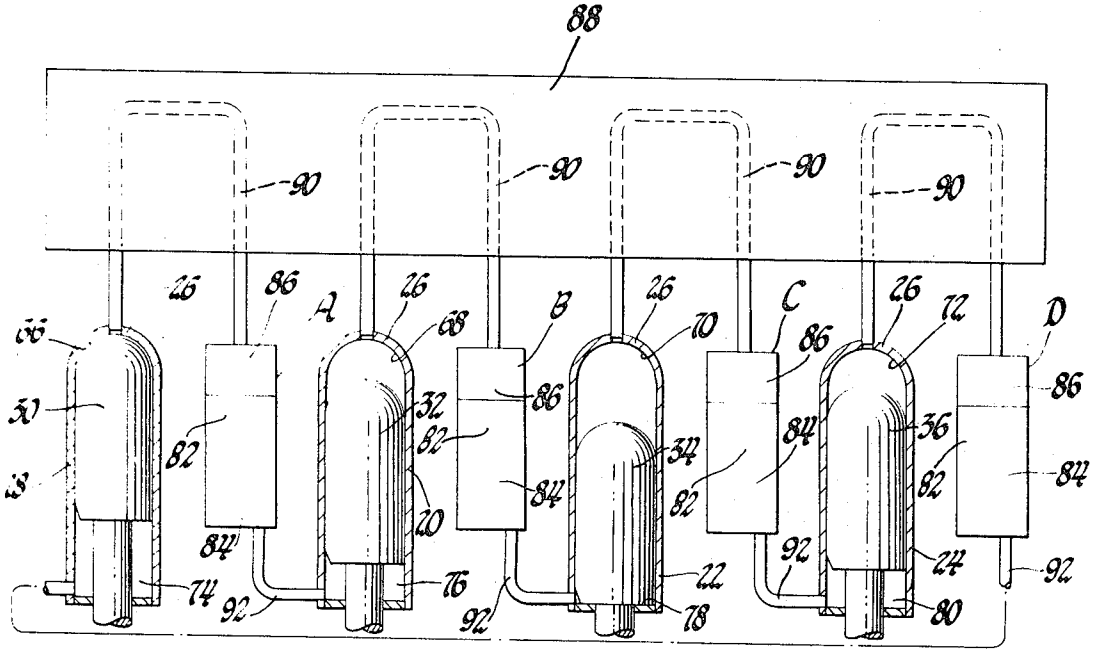


Fig. 3

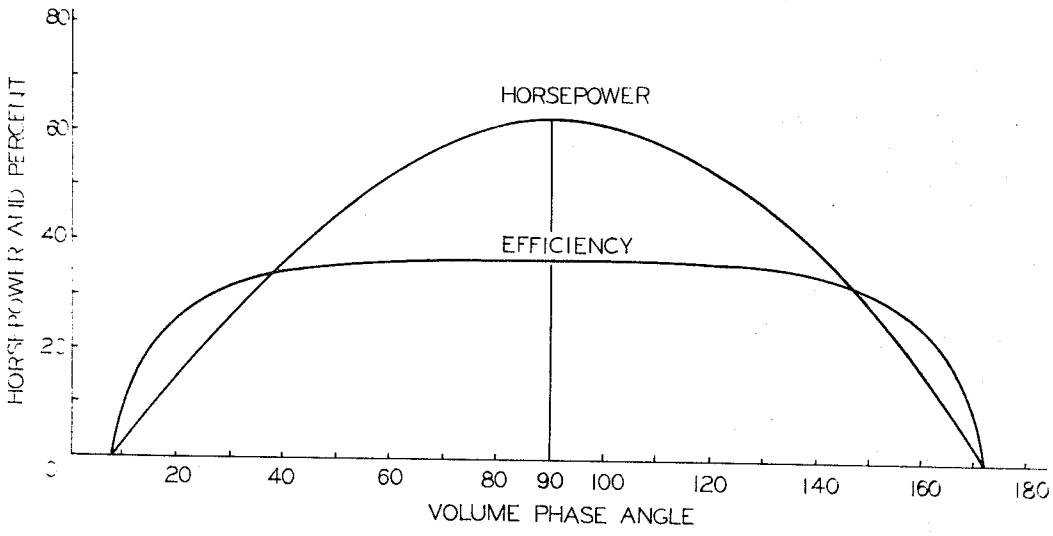


Fig. 4

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MULTICYLINDER HOT GAS ENGINE WITH POWER CONTROL

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ABSTRACT OF THE DISCLOSURE

In a preferred embodiment, a four-cylinder double acting hot gas engine has annularly arranged axially disposed cylinders interconnected to form four working spaces each defined by two adjacent pistons. The pistons are alternately connected to a pair of swash plates which drive an output shaft through a phase changing gear box. Relative rotation of the swash plates by the phase changer adjusts the phase relationships of the various pistons to control the engine power output.

FIELD OF THE INVENTION

My invention relates to hot gas engines and more particularly to means for controlling the power output in certain multicylinder engines of the hot gas type.

DESCRIPTION OF THE PRIOR ART

It is known in the art relating to certain types of hot gas engines to vary the power output by adjusting the phase relationships of the pistons which act upon the working gas so as to carry out a thermodynamic work producing cycle. Such an arrangement is, for example, shown in U.S. Pat. No. 2,465,139 Van Weenen et al. as applied to a single cylinder engine having a power piston which varies the volume of the working space and a displacer piston which moves the gas between the cold and hot zones of the working space.

It is obvious that such phase changing arrangements could be applied to multi-cylinder engines of the type shown in the aforementioned patent merely by changing the phase relationships of all the similar pistons in the same manner. There are, however, other multicylinder engine constructions, for example, those disclosed in the various figures of U.S. Pat. No. 2,480,525 Van Weenen to which such phase changing concepts are not obviously applicable. In these latter engines, there is no single displacer piston, but two pistons acting together serve the dual functions of controlling the volume of the working space and transferring the working gas back and forth between the hot and cold zones or chambers.

Further, in most of these designs, a single piston is made to act upon the working gas in two separate working spaces giving what is known as a double acting piston or a double acting engine arrangement. In these double acting arrangements, each cylinder is interconnected with two others so that it is impossible to adjust the phase relationships of all the working cycles in the same manner. This results from the fact that movement of one piston to bring it more in phase with a second piston with which it acts to define one working space will move the first piston further out of phase with a third piston with which it acts to define a second working space.

SUMMARY OF THE INVENTION

The present invention provides arrangements by which the power output of a hot gas engine having one or more double acting piston may be controlled by varying the phase relationships of the engine pistons. While the invention is broadly applicable to many types of engines in which two pistons acting together control the volume of each working space, an engine arrangement is proposed which is especially suitable for use with the fundamental inventive concepts.

The basis for the present invention was the discovery, proven by theoretical studies, that the horsepower and efficiency curves for a hot gas engine follow relatively uniform patterns from their maximum to zero as the phase angle between the hot and cold chambers of the working spaces is adjusted in either direction from one-quarter cycle (90 degrees) out of phase to either an in phase condition or to a one-half cycle (180 degrees) out of phase condition. This was found to be true even though the pressure and volume conditions differ when moving in the two opposite directions and this discovery led to the realization that adjusting the phase of one piston of a multicylinder double acting engine away from the conventional one-quarter cycle out of phase relationship between the pistons of its connecting cylinders would act to reduce the power output in both its connected working spaces in about the same degree.

The present invention, therefore, makes use of this phenomenon by providing drive means which permit adjusting the phase relationships of alternate pistons of the interconnected cylinders of a double acting engine so as to control the power output. As a preferred embodiment, a four-cylinder axial piston arrangement utilizing dual swash plate drive is proposed for advantageous application of the novel concept.

These and other advantages of the invention will be more apparent from the following description of the preferred embodiment taken together with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a side elevational view, partially in cross section, of a preferred embodiment of a hot gas engine formed according to the invention;

FIG. 2 is a cross-sectional view of the hot gas engine of FIG. 1 taken generally in the plane indicated by the line 2—2 of the figure;

FIG. 3 is a diagrammatic view of the hot gas engine of FIGS. 1 and 2 showing the interrelationship of the various components making up the engine working spaces and

FIG. 4 is a graph indicating the curves of horsepower and efficiency at various phase angles between the volumes of the hot and cold chambers of a working space.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the figures of the drawings in detail, numeral 10 generally indicates a four-cylinder axial piston hot gas engine having a drive housing 12 to which are attached four seal retainers 14 secured by collars 16 to four cylinder members 18, 20, 22 and 24 annularly arranged on parallel axes. The cylinders terminate in closed ends 26 and may include liners 28 in which are reciprocably disposed four pistons 30, 32, 34 and 36. The pistons carry suitable seal rings 38 and are connected by rods 40 to follower members 42 and 43 which reciprocate in sleeves 44 provided in the housing 12. Rolling seals 46 are provided between the seal retainers 14 and rods 40 to prevent the escape of working gas from the cylinders into the drive housing.

Within the drive housing are a pair of swash plates 48 and 50 carried for rotation on concentric shaft members 52 and 54 respectively. Swash plate 48 is connected to a first group of two pistons 32 and 36 by sliding engagement with pivotable bearing members 56 which and

seated on the sides of slots **58** of the follower members **43** connecting with these pistons. Swash plate **50** connects to a second group of two pistons **30** and **34** in a similar manner through their respective bearing members **56** and follower members **42**. Additional elongated slots **60** are provided in follower members **42** and **43** to provide clearance for the rotation of the swash plates **48** and **50** within the follower members to which they are not connected.

Shaft members **52** and **54** extend into a gear box **62** which contains suitable phase changing mechanism for varying the rotative portions of swash plates **48** and **50**. By the phase changer **62**, shaft members **52, 54** are interconnected with one another and are both connected so as to supply power to an output shaft **64**.

The interiors of the engine cylinders **18, 20, 22** and **24** are separated by their respective pistons into hot chambers **66, 68, 70** and **72** formed at the ends **26** of the cylinders and cold chambers **74, 76, 78** and **80** formed at the opposite ends thereof. Annularly disposed intermediate the cylinders are four canister-like members **82** each of which includes a suitable cooler **84** and a regenerator **86**. A heater **88**, which may be a burner or other suitable heating device, is located outboard of the ends **26** of the engine cylinders. A plurality of tubes **90** extend from the ends **26** of the cylinders through heater **88** to the regenerator **86** of the adjacent canister. Short connectors **92** connect the cooler ends of the canisters with the cold chamber ends of the adjacent cylinders.

Thus, four separate gas containing working spaces A, B, C and D are formed, each made up of the hot and cold chambers of adjacent cylinders connected through certain heater tubes **90**, a regenerator **86** and its connecting cooler **84** and one of the short connectors **92**. The volume of each working space varies as determined by the positions of the two pistons which define it, one of these pistons varying the volume of the hot chamber and the other varying the volum of the cold chamber. Each double acting piston, in turn, defines both a hot and a cold chamber which form parts of two separate working spaces.

FIG. 4 shows the calculated effects on horsepower and efficiency of changing the volume phase angle of the hot and cold chambers of one working space. That these relationships are not completely obvious is apparent from a consideration of the differing results obtained from changing the phase angle in opposite directions from the nominal 90 degrees.

The normal working cycle includes events of compression, heating, expansion and cooling. The heating and cooling events take place by the transfer of gas from the cold chamber through the cooler, regenerator and heater to the hot chamber and vice versa. Reducing the phase angle of the volume changes of the hot and cold chambers to zero increases both compression and expansion but substantially eliminates gas transfer between the chambers. Increasing the phase angle to 180 degrees increases gas transfer but eliminates compression and expansion. While both acts reduce power output to zero, the differences in the method of reduction make surprising the similarity in the shape of the two halves of the power curves. Possibly even more surprising is the relatively high efficiency indicated for all but the lower power levels.

In normal full output operation of the engine, the four pistons are reciprocated continuously but with adjacent pistons having a 90 degree or one-quarter cycle phase difference from one another. As shown in FIG. 3, the pistons follow one another in the sequence **36, 34, 32, 30** with one-quarter cycle between them. This results in the cycle of volume changes of the respective hot chambers leading the volume changes of their connected cold chambers by 90 degrees or one-quarter cycle which gives a positive work output at a maximum power level for each working space. This work output is transferred by the pistons to their connected swash plates **48, 50** and thence through the phase changer **62** to the output shaft **64**.

In order to reduce the engine power output, the phase changer **62** is operated by control means, not shown, so as to rotate either one or both of the swash plates as described through an angle of up to 90 degrees with respect to one another. This changes the phase relationships of the various pistons.

Thus, for example, the position of piston **36** may be retarded one-quarter cycle or 90 degrees which will put this piston in phase with piston **34**. At the same time, piston **32** will be moved 90 degrees in a retarding direction so that it is in phase with piston **30** and 180 degrees or one-half cycle out of phase with piston **34**. Pistons **36** and **30** will also be 180 degrees or one-half cycle out of phase with one another. By this adjustment, the hot and cold chambers of working spaces B and D change from 90 degree phase angles to phase angles of zero. This reduces the power output of these working spaces as shown in the left hand portion of the curve of FIG. 4 from a maximum to zero. At the same time, the hot and cold chambers of working spaces A and C have their phase angles increased from 90 degrees to 180 degrees, which reduces the power of these working spaces as shown in the right hand side portion of the curve of FIG. 4 from a maximum to zero. It should be obvious that any intermediate adjustment of the phase angle will result in an intermediate power output from the engine with approximately equal power outputs being obtained from each of the working spaces as indicated by the uniform shape of both sides of the horsepower curve of FIG. 4.

While the invention has been described by reference to a preferred embodiment chosen for purposes of illustration, it should be apparent that the concepts involved are equally applicable to other hot gas engines in which double acting cylinder arrangements may be used. For example, the phase changing concepts disclosed herein could equally well be applied to any of the engines shown in the various figures of the previously mentioned U.S. Pat. No. 2,480,525, the disclosure of which is hereby incorporated herein by reference. Many other modifications of the invention within the spirit and scope of the inventive concepts presented should also be obvious to those skilled in the art.

What is claimed is:

1. A hot gas engine adapted to operate with a gaseous working fluid and comprising

a plurality of cylinders,

a plurality of pistons not less than three in said engine cylinders and defining therewith at least two hot chambers and at least two cold chambers, the volume of each of said chambers being determined by the operative position of one of said pistons,

passage means connecting each hot chamber defined by one of said pistons with a cold chamber defined by another of said pistons to form a plurality of working spaces each having the volume thereof determined by the operative positions of two pistons,

said pistons being classifiable into first and second groups each consisting of one only of the pistons determining the volume of each of said working space, each group defining at least one hot chamber and at least one cold chamber,

first and second drive means connected with the pistons of said first and second groups respectively and operative to maintain predetermined phase relationships between the pistons of said first group and between the pistons of said second group, said drive means being adapted to maintain a controlled phase relation between said pistons for operation at maximum engine power such that the volume change of each hot chamber leads the volume change of the cold chamber of its respective working space by one-quarter of a cycle,

said second drive means being adjustable with respect to said first drive means to reduce engine power by unidirectionally changing the phase relations of the pistons of said second group with respect to the

pistons of said first group by an amount up to one-quarter of a cycle, said one-quarter cycle change resulting in the volume changes of the hot chambers of certain working spaces being in phase with the volume changes of the respective cold chambers thereof while the volume changes of the hot chambers of the remaining working spaces are one-half cycle out of phase with the volume changes of the respective cold chambers thereof, each such condition resulting in no power output from the pistons of the various working spaces.

2. The combination of claim 1 wherein said engine has four cylinders each having one double acting piston therein, two of said pistons being connected to said first drive means and two of said pistons being connected to said second drive means.

3. The combination of claim 2 wherein said engine cylinders are annularly arranged on parallel axes and said drive means comprise first and second swash plates.

4. A hot gas engine adapted to operate with a gaseous working fluid and comprising

four cylinders,

a double acting piston in each cylinder and defining therewith a hot chamber at one end and a cold chamber at the other, the volume of each of said chambers being determined by the operative position of said piston,

passage means connecting the hot chamber of each cylinder with the cold chamber of another to form a plurality of working spaces each having the volume thereof determined by the operative positions of the two pistons,

said pistons being classifiable into first and second groups each consisting of two pistons which together determine, in part, the volume of all of said working spaces,

first and second drive means connected with the pistons of said first and second groups respectively and operative to maintain an out of phase relationship between the pistons of said first group and between the pistons of said second group, said drive means being adapted to maintain a one-quarter cycle phase angle between the pistons of said first and second groups for operation at maximum engine power such that the volume change of each hot chamber leads the volume change of the cold chamber of its respective working space by one-quarter of a cycle,

said second drive means being adjustable with respect to said first drive means to reduce engine power by unidirectionally changing the phase relations of the pistons of said second group with respect to the pistons of said first group by an amount up to one-quarter of a cycle, said change resulting in a decrease in the phase angle between the hot and cold chambers of two of said working spaces and a comparable increase in the phase angle between the

hot and cold chambers of the other two of said working spaces.

5. The combination of claim 4 wherein said engine cylinders are annularly arranged on parallel axes and said working spaces are formed by connection together of adjacent cylinders, said first and second groups consisting of oppositely disposed pistons.

6. The combination of claim 5 wherein said drive means comprise first and second swash plates rotatable on a common axis, and relatively rotatable to vary the phase relationships of the first and second groups of pistons.

7. The method of controlling the power output of a multicylinder hot gas engine having a plurality of pistons and a plurality of working spaces each including a hot chamber defined in part by one of said pistons in a cold chamber defined in part by another of said pistons, said method comprising the steps of

controlling the phase relations of said pistons during reciprocation thereof to obtain a leading phase angle of one-quarter cycle for the volume variations of the hot chamber of each working space over the cold chamber thereof for maximum engine power and

reducing engine power by changing the phase relations of the pistons to decrease the leading phase angles of the hot chambers over the cold chambers of certain of the engine working spaces up to a maximum decrease of one-quarter cycle to an in-phase condition, while concurrently increasing the leading phase angles of the hot chambers over the cold chambers of the remaining engine working spaces in a comparable amount up to a maximum increase of one-quarter cycle to a one-half cycle out-of-phase condition.

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U.S. Cl. X.R.

91—175, 199; 103—37