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(54) **Control system for the injection pressure of a fuel injector for a diesel cycle engine**

Einspritzdruckregeleinrichtung eines Kraftstoffeinspritzventils für Dieselmotoren

Système de réglage de pression d'injection d'un injecteur à combustible pour un moteur diesel

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EP-A- 0 413 454

- **PATENT ABSTRACTS OF JAPAN vol. 11, no. 247 (M-615)12 August 1987 & JP-A-62 055 455 (DIESEL KIKI CO. LTD.) 11 March 1987**

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Description

The present invention relates to a control system for the injection pressure of an electromagnetically actuated fuel injector for a diesel cycle engine, by means of which it is possible to obtain relatively high maximum injection pressures even at low speeds of rotation of the engine and fuel flow rates which increase gradually during each injection cycle.

In a fuel injection system for a diesel cycle engine use is normally made of injectors, each of which comprises an injection piston, moving at a speed which normally increases proportionally to the speed of rotation of the engine and which is adapted to inject the fuel via an injection hole controlled by an electromagnetically actuated shutter member; this shutter member is adapted to open this injection hole when the piston has performed a predetermined stroke.

The injection piston of each injector is normally controlled by a cam carried by a camshaft actuated by the engine. The profile of this cam is normally selected in order to control the piston so that it moves, during its entire forward stroke, at a speed which increases proportionally to the angle of rotation of this cam and in order to control the piston so that it moves, during its return stroke, at a speed which decreases proportionally to the angle of rotation of the cam. In a system of this type, therefore, the diagram representing the development of the speed of the injection piston as a function of the angle of rotation of the cam, in each injection cycle, is formed by a continuous curve with two rectilinear sides, one of whose values increase and the other of whose values decrease in a linear manner as the angle of rotation of the cam increases.

With injection pressure control systems of the above-mentioned type, the fuel pressure within the injector increases, during the forward stroke of the injection piston, until it reaches the maximum value; thereafter, the pressure decreases, during the return stroke of the piston, until it is cancelled out. The value of this maximum pressure is more or less directly proportional to the value of the maximum speed of the piston and inversely proportional to the cross-section of the injection hole.

Injection pressure control systems as described above have certain drawbacks.

In the first instance, the ratio between the maximum fuel pressures obtained during injection cycles corresponding to two different speeds of rotation of the engine is rather high; when these two speeds are, for instance, equivalent to 2000 and 1000 revolutions per minute respectively, this ratio is approximately 2.

Moreover, the fuel is injected in a rather abrupt manner, since the rates of flow of the fuel injected by unit of angular rotation are rather high, with the result that there is unsatisfactory mixing and combustion of the fuel, and likely to cause very high pressures in the combustion chamber and to form non-combusted material.

EP-A-0 413 454 discloses a control system for the injection pressure of a fuel injector, the features of which form the basis of the preamble of claim 1. However, such a control system does not solve the aforesaid problems completely.

The object of the present invention is to provide a control system for the injection pressure of a fuel injector for a diesel cycle engine which remedies the drawbacks described above.

This object is achieved by a control system for the injection pressure of an electromagnetically actuated fuel injector for a diesel cycle engine as claimed in claim 1.

The control system of the invention is set out in further detail in the following description made with reference to the accompanying drawings, in which;

Fig. 1 is a vertical section through the head of a diesel cycle engine showing the fuel injector and the associated actuation device;

Figs. 2 and 3 show, as a function of the angle of rotation of the cam actuating the injector, the development of the speed of advance of the injector piston and the injection pressure obtained thereby, in a traditional injection system and an injection system of the invention respectively;

Figs. 4 and 5 show, as a function of the angle of rotation of the above-mentioned cam, the development of the speed of advance of the piston and the rate of flow per unit of angular rotation of the cam, in a traditional injection system and an injection system of the invention respectively.

The injection pressure control system of the invention may be embodied in a diesel cycle engine of the type shown in Fig. 1, which substantially comprises an injector, shown overall by 1, of a conventional electromagnetically actuated type, in whose housing an injection piston (not shown) moves; this injector is adapted to inject fuel via an injection hole 2 provided on the head 3 of the engine; the injection hole 2 is controlled by a moving shutter member (not shown) which opens the injection hole when the shutter member is displaced by the action of an electromagnet under the effect of an excitation command.

The injector 1 is actuated by a rocker arm 4 oscillating about a shaft 5 and is provided with a pair of arms 6 and 7, the first of which is able to exert, via appropriate transmission members, predetermined forces on the piston of the injector 1 in order to pressurize the fuel contained therein; the other arm 7 of the rocker arm 4 is provided with a roller 8 adapted to bear on the profile 9 of a cam 10 borne by a camshaft 11 actuated by the engine.

The injector 1 is secured to the head 3 by appropriate connection members, some of which are shown in Fig. 1.

In control systems for the injection pressure of the injector 1 of a known type, during each injection cycle, the injection piston with which the injector 1 is provided is caused to advance (by appropriate selection of the profile 9 of the cam 10) during its entire forward stroke at a speed which increases proportionally to this stroke and, therefore, at a speed which increases proportionally to the angle of rotation of the cam 10; moreover, during the return stroke of this piston, the speed of return of the piston is caused to decrease substantially proportionally to the stroke and, therefore, proportionally to the angle of rotation of the cam 10. Fig. 2 shows the development of the speed of the injection piston during its forward stroke (shown by the line t) and during its return stroke (shown by the line t') as a function of the angle of rotation of the cam 10). It will be appreciated from this Figure that the development of the speed, as a function of the angle of rotation of the cam, may be approximately shown by a triangular diagram having predetermined sides t and t'.

In the case of the injection pressure control system of the invention, during each injection cycle the injection piston is caused to advance over a first portion of its forward stroke at a speed which increases proportionally to this stroke, over a second portion of its stroke at a speed which is constant and over a third portion of this stroke at a speed which again increases proportionally to the stroke.

When the movement of the injection piston is controlled by a cam 10 borne by a camshaft 11 actuated by the engine, as shown in the embodiment of the invention, the profile 9 of the cam 10 is selected to control the injection piston so that it moves, during each injection cycle, over a first portion of its forward stroke at a speed which increases proportionally to the angle of rotation of the cam, over a second portion of its stroke at a speed which is constant as this angle increases and over a third portion of its stroke at a speed which again increases proportionally to the angle of rotation of the cam. In Fig. 3, the lines t_1, t_2 and t_3 represent the development of the speed of the injection piston as a function of the angle of rotation of the cam in the three forward stroke portions as defined above: it can be seen that while the initial and final portions (lines t_1 and t_3) of the piston stroke are travelled at speeds which increase in a linear manner, the intermediate stroke portion (line t_2) is travelled at a constant speed.

The system of the invention further comprises appropriate actuation means able to control the movement of the shutter member of the injector in order to open the injection hole 2 at any point during the forward stroke of the injector piston and, therefore, after this piston has performed a predetermined stroke.

In accordance with the invention, during each injection cycle and for a first predetermined speed of rotation of the engine n_1, the predetermined stroke of the piston at which the opening of the shutter member of the injector is controlled and fuel injection consequently begins, is selected along the first portion of the forward stroke of the piston and therefore at a point of the peak t_1 shown by A in Fig. 3; moreover, during each injection cycle and for a predetermined second speed of rotation of the engine n_2 lower than the first speed n_1, the above-mentioned predetermined stroke of the piston, at which opening of the shutter member of the injector is controlled and fuel injection consequently commences, is selected along the second portion of the forward stroke of the piston and therefore at a point of the line t_2 shown by B in Fig. 3.

The second predetermined speed n_2 is advantageously between 30 and 70% of the first predetermined speed n_1; these speeds may, for instance, be equal to 2000 and 1000 revolutions per minute respectively.

Moreover, the angle of rotation of the cam 9 during the second portion of the forward stroke of the injection piston, shown by the line t_2, is between 15% and 25% of the angle of rotation of the cam which is needed to perform the entire forward stroke of the piston (represented by the sum of the lines t_1, t_2 and t_3).

In order to understand the operating methods which may be achieved with the pressure control system of the invention as described above, it is appropriate in the first instance to examine the results which can be obtained with conventional control systems in which a forward stroke of the injection piston of the injector 1 takes place proportionally to the angle of rotation of the cam shown by the rectilinear line t of Fig. 2.

It is supposed that two different injection cycles are carried out, each of which is obtained for one of the two predetermined speeds as defined above n_1, n_2, equivalent for instance to 2000 and 1000 revolutions per minute; during the rotation of the cam 10 the forward stroke of the injector piston is controlled at a speed which increases as the angle of rotation of the cam increases with the development provided by the peak t and until the maximum value V_{max} is achieved; as rotation of the cam continues, the speed V decreases according to the development of the peak t'.

As a result, the fuel pressure increases as the stroke of the piston increases in each of the two cycles with a development which is shown by the curves p_1 and p_2 of Fig. 2. In these diagrams it is supposed that the opening of the injector, and therefore the commencement of injection, is controlled on achievement of the pressure p_o, to which the points A and B of the curve t correspond.

An examination of these curves shows that the fuel injection takes place at pressures which increase rather abruptly as the angle of rotation of the cam increases and that the value of the maximum pressure achieved in both cases is very different: in the case of the example examined, the ratio between the two maximum pressures is approximately 2. This means that when the maximum pressure corresponding to the first reference speed n_1 has been selected in order achieve the maximum value compatible with the injection system, the maximum pressure which may be obtained with the second speed

n_2 may be too small efficiently to atomize the fuel; moreover, the overly abrupt increase of the pressure during the injection stage may have an adverse effect on the mixing and combustion of the fuel.

The following operating methods are achieved with the system of the invention as described above and can be seen from the diagrams of Fig. 3.

It is again supposed that two different injection cycles are carried out, the first of which is obtained for one of the two predetermined speeds of rotation of the engine defined above (2000 revolutions per minute) and the second for the second of these speeds (1000 revolutions per minute).

In order correctly to compare the results shown in Fig. 2, it is also supposed that the diagram of the speed of advance of the piston as a function of the angle of rotation of the cam 10 includes sections t_1 and t_3 (Fig. 3) having the same gradient as the line t of Fig. 2, that the lines t' of Figs. 1 and 3 have the same gradient and lastly that the active angle of rotation of the cam 10 is the same in both cases (60°). This means that as a result of the presence of the horizontal section t_2 of constant speed, the maximum speed of the piston (V_{max}) is, in the case of the invention, lower than the corresponding maximum speed obtained with the conventional control system of Fig. 2.

In each of the two cycles defined above the fuel injection pressure increases with the development shown by the curves p_1 and p_2; if it is supposed that injection commences in each of the two cycles when the pressure p_o is reached, in the case of the first cycle the point A corresponds to this pressure on the curve t_1 and in the case of the second cycle the point B corresponds to the same pressure on the curve t_2. The development of the injection pressure p_1 in the first cycle is therefore particularly influenced by the presence of the portion of the stroke with a constant speed shown by the section t_2 of the curve, while the development of the injection pressure p_2 in the second cycle is only partially influenced by this section, starting injection at the point B located at the end of the section t_2.

As a result of this it has been observed that with the system of the invention the maximum pressures measured on the curves p_1 and p_2 which are achieved with the two different reference speeds do not differ to a marked extent and differ much less than in the case of the conventional pressure control system described above; in particular, under the same operating conditions used to obtain the results of Fig. 2, the ratio between these maximum pressures is reduced to 1.6 - 1.7.

A comparison of the development of the rising sections of the curves p_1 and p_2 of Fig. 3 and those of Fig. 2 also shows that the pressure increases less abruptly in both cases.

Moreover, at the same maximum injection pressure achieved with the reference speed n_1, the system of the invention makes it possible to achieve this pressure with a cross-section of the injection hole of the injector which is smaller than that needed with the conventional system. This result can be seen from a ccmparison of the curves of Figs. 2 and 3 in which the maximum value of the pressures p_1 is the same (and may correspond to that compatible with the mechanical strength of some components of the systems): in order to achieve this result, the system of the invention uses an injector whose injection hole has smaller dimensions that those of the injector used in the conventional system. This result can be explained by taking account of the fact that the injection pressure is directly proportional to the maximum speed (V_{max}) of advance of the piston and inversely proportional to the cross-section of the injection hole and that V_{max} is smaller in the case of the system of the invention as has already been pointed out above.

It has also been observed that, under the same operating conditions, in the case of the system of the invention the stroke of the piston during which fuel injection takes place is higher than that obtained with the conventional system; this can be seen from a comparison of the angles of rotation of the cam 10 shown by the curves p_1 and p_2 of Figs. 2 and 3. It follows from this that the injection of the fuel is more gradual with the system of the invention.

This can also be seen from Figs. 4 and 5 which show the developments of the rates of flow per unit of angular rotation of the cam 10 as a function of the angle of rotation of this cam, respectively in the case of the conventional pressure control system and that of the invention (Fig. 5). The curves shown by q_1 and q_2 in these Figures show the rates of flow of fuel injected obtained respectively at the two above-mentioned reference speeds n_1 and n_2. A comparison of the diagrams of these Figures shows that with the control system of the invention the rate of introduction of the fuel into the cylinders is much more gradual with the advantage that more regular and more complete combustion of the fuel is obtained.

It is evident that modifications and variants may be made to the injection pressure control system of the invention. In particular, the movement of the injection cylinder of the injector 1 may be obtained using a kinematic mechanism differing from that shown, comprising the rocker arm 4 and the cam 10, provided that a rate of variation of the speed of the piston as a function of its stroke of the type described and illustrated is provided.

Claims

1. A control system for the injection pressure of an electromagnetically actuated fuel injector (1) for a diesel cycle engine, this injector comprising an injection piston moving at a speed which increases proportionally to the speed of rotation of engine and being provided with a moving shutter member adapted to open an injection hole (2) in order to inject the fuel when the piston has performed a pre-

determined stroke; during each injection cycle, the injection piston being caused to advance over a first portion of its forward stroke at a speed increasing proportionally to this stroke, over a second portion of its stroke at a constant speed and over a third portion of its stroke at a speed which again increases proportionally to the stroke, characterized in that, during each injection cycle and for a first predetermined speed of rotation of the engine (n_1), the predetermined stroke of the piston at which injection of the fuel commences is selected along the first portion of the forward stroke of the piston and, for a second speed of rotation of the engine (n_2) lower than the first predetermined speed, the predetermined stroke of the piston at which injection of the fuel commences is selected along the second portion of the forward stroke of the piston.

2. A system as claimed in one of the preceding claims, characterized in that the second predetermined speed (n_2) is between 30% and 70% of the first predetermined speed (n_1).

3. A system as claimed in one of the preceding claims, in which the moving piston is controlled by a cam (10) borne by a camshaft (11) actuated by the engine.

4. A system as claimed in claim 3 characterized in that the profile (9) of the cam (10) is selected in order to control the piston so that it moves, during its return stroke, at a speed which decreases proportionally to the angle of rotation of the cam.

5. A system as claimed in one of claims 3 or 4, characterized in that the angle of rotation of the cam (10) during the second portion of the forward stroke of the piston is between 15% and 25% of the angle of rotation of the cam which is needed to perform the entire forward stroke of this piston.

Patentansprüche

1. Steuerungssystem für den Einspritzdruck eines elektromagnetisch betätigten Kraftstoffeinspritzventils (1) für einen Dieselmotor, wobei dieses Einspritzventil einen Einspritzkolben aufweist, der sich bei einer Geschwindigkeit bewegt, die sich proportional zu der Drehgeschwindigkeit des Motors vergrößert und mit einem sich bewegenden Verschlußelement versehen ist, das derart gestaltet ist, daß eine Einspritzöffnung (2) geöffnet wird, um den Kraftstoff einzuspritzen, wenn der Kolben einen vorbestimmten Hub durchgeführt hat; wobei der Einspritzkolben während eines jeden Einspritzzyklus veranlaßt wird, sich über einen ersten Abschnitt seines Vorwärtshubes bei einer Geschwindigkeit voranzubewegen, die sich proportional zu diesem Hub vergrößert, sich über einen zweiten Abschnitt seines Hubes bei einer konstanten Geschwindigkeit voranzubewegen, und sich über einen dritten Abschnitt seines Hubes bei einer Geschwindigkeit voranzubewegen, die sich wiederum proportional zu dem Hub vergrößert,
dadurch **gekennzeichnet** , daß
während eines jeden Einspritzzyklus und für eine erste vorbestimmte Drehgeschwindigkeit des Motors (n_1) der vorbestimmte Hub des Kolbens, bei dem die Kraftstoffeinspritzung beginnt, entlang des ersten Abschnitts des Vorwärtshubes des Kolbens gewählt wird, und daß für eine zweite Drehgeschwindigkeit des Motors (n_2), die geringer ist als die erste vorbestimmte Geschwindigkeit, der vorbestimmte Hub des Kolbens, bei dem die Kraftstoffeinspritzung beginnt, entlang des zweiten Abschnitts des Vorwärtshubes des Kolbens gewählt wird.

2. System nach Anspruch 1,
dadurch **gekennzeichnet**, daß
die zweite vorbestimmte Geschwindigkeit (n_2) zwischen 30% und 70% der ersten vorbestimmten Geschwindigkeit (n_1) liegt.

3. System nach Anspruch 1 oder 2,
wobei der sich bewegende Kolben durch einen Nocken (10) gesteuert wird, der durch eine Nockenwelle (11) getragen wird, die durch den Motor betätigt wird.

4. System nach Anspruch 3,
dadurch **gekennzeichnet,** daß
das Profil (9) des Nockens (10) so gewählt wird, daß der Kolben derart gesteuert wird, daß er sich während seines Rückhubes bei einer Geschwindigkeit bewegt, die sich proportional zu dem Drehwinkel des Nockens verringert.

5. System nach einem der Ansprüche 3 oder 4,
dadurch **gekennzeichnet**, daß
der Drehwinkel des Nockens (10) während des zweiten Abschnitts des Vorwärtshubes des Kolbens zwischen 15% und 25% des Drehwinkels des Nockens liegt, der für die Durchführung des gesamten Vorwärtshubes des Kolbens erforderlich ist.

Revendications

1. Un système de réglage de la pression d'injection d'un injecteur de carburant à actionnement électromagnétique (1) pour un moteur diesel, cet injecteur comprenant un piston d'injection se déplaçant à une vitesse qui augmente proportionnellement à la vitesse de rotation du moteur et étant pourvu d'un organe obturateur mobile apte à ouvrir un orifice d'injection (2) pour injecter le carburant lorsque le piston a effectué une course prédéterminée; le piston d'injection étant, au cours de chaque cycle d'injection, contraint d'avancer sur une première partie de sa course d'avancement à une vitesse qui augmente proportionnellement à cette course, sur une deuxième partie de sa course à une vitesse constante, et sur une troisième partie de sa course à une vitesse qui augmente à nouveau proportionnellement à la course, caractérisé en ce que, pendant chaque cycle d'injection et pour une première vitesse de rotation prédéterminée du moteur (n_1), la course prédéterminée du piston à laquelle commence l'injection du carburant est choisie sur la première partie de la course d'avancement du piston et, pour une deuxième vitesse de rotation du moteur (n_2), inférieure à la première vitesse prédéterminée, la course prédéterminée du piston à laquelle commence l'injection du carburant est choisie sur la deuxième partie de la course d'avancement du piston.

2. Un système selon l'une des précédentes revendications, caractérisé en ce que la deuxième vitesse prédéterminée (n_2) est entre 30% et 70% de la première vitesse prédéterminée (n_1).

3. Un système selon l'une des précédentes revendications, dans lequel le piston mobile est commandé par une came (10) portée par un arbre à cames (11) entraîné par le moteur.

4. Un système selon la revendication 3, caractérisé en ce que le profil (9) de la came (10) est choisi afin d'agir sur le piston d'une manière telle qu'il se déplace, pendant sa course de retour, à une vitesse qui baisse proportionnellement à l'angle de rotation de la came.

5. Un système selon l'une des revendications 3 ou 4, caractérisé en ce que l'angle de rotation de la came (10) pendant la deuxième partie de la course d'avancement du piston est entre 15 % et 25 % de l'angle de rotation de la came qui est nécessaire pour effectuer la totalité de la course d'avancement de ce piston.

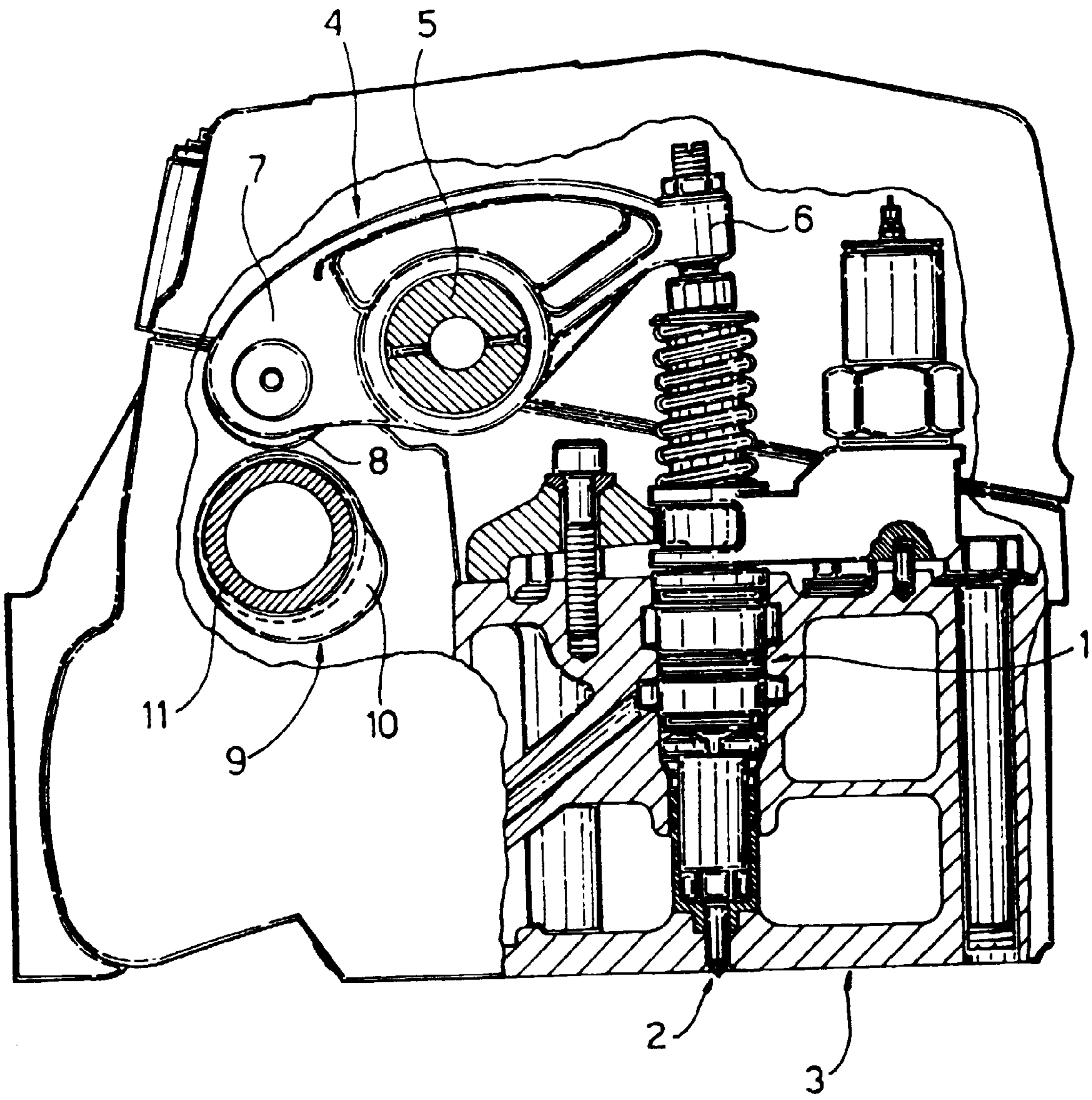


Fig.1

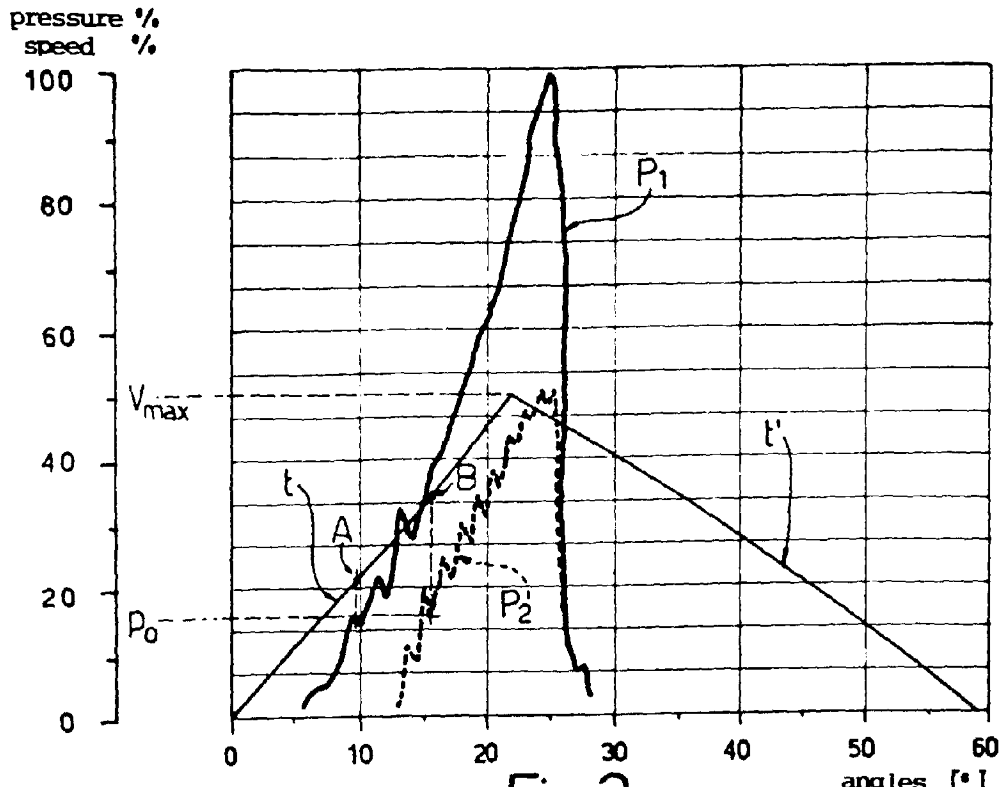
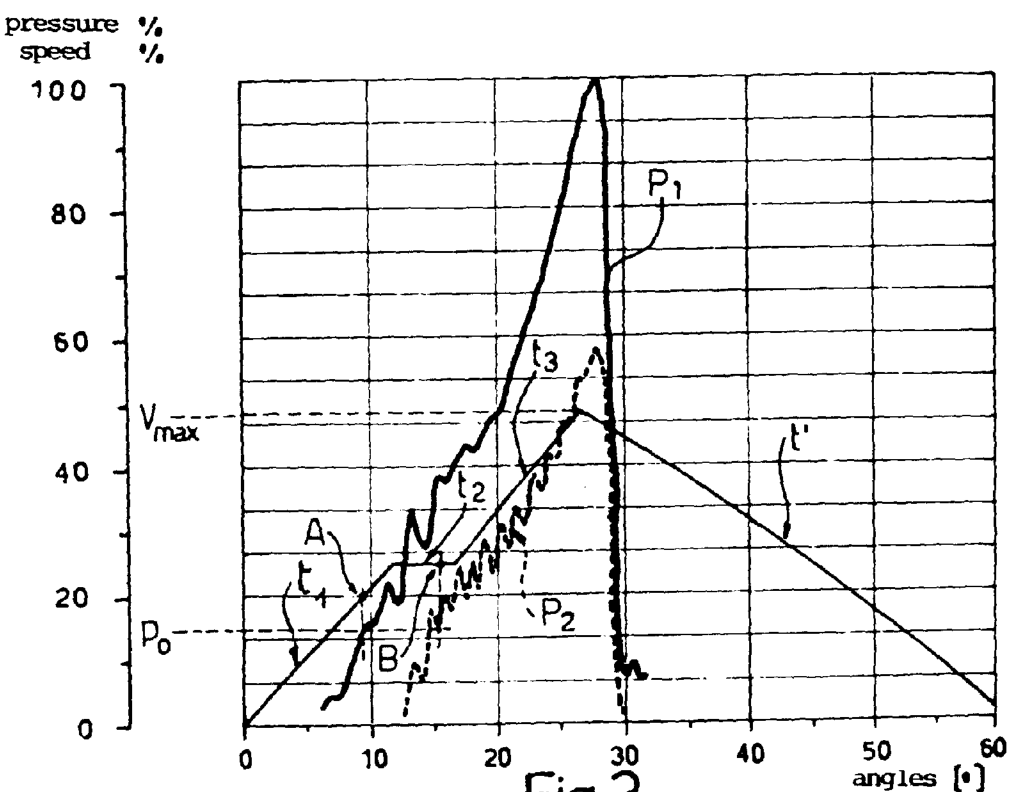

pressure %
speed %
100
80
60
40
20
0
Vmax
P0
t
A
B
P1
P2
t'
0
10
20
30
40
50
60
angles [°]

Fig.2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60
40
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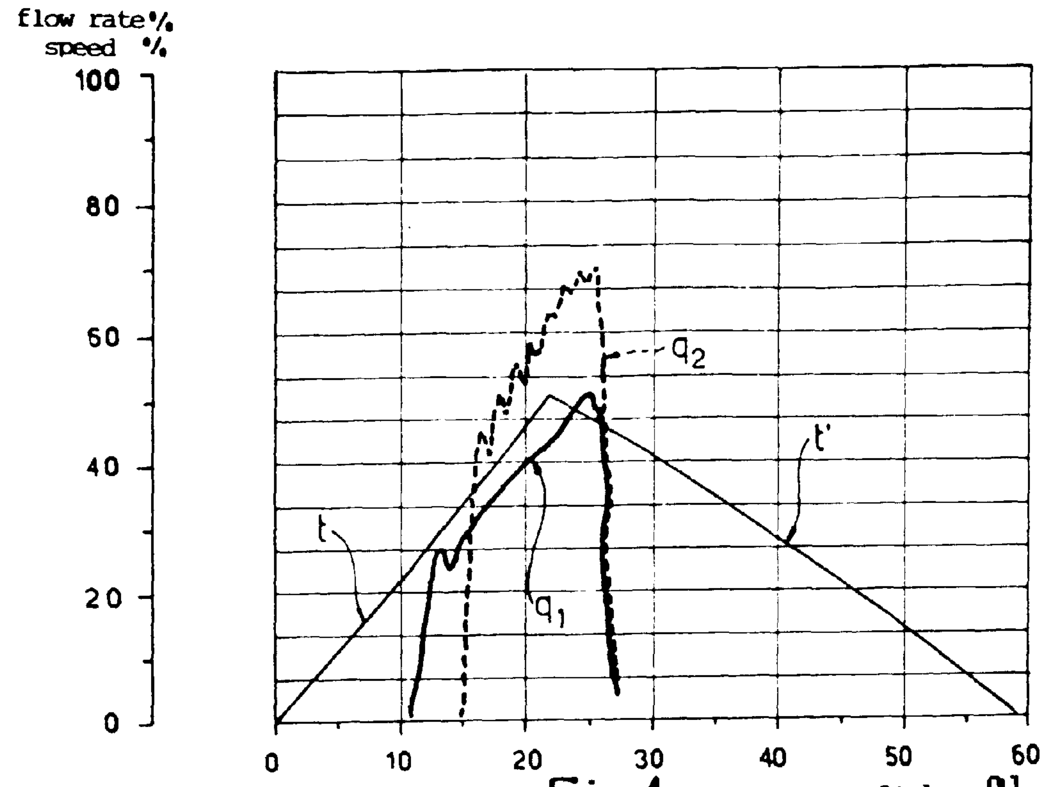
Vmax
P0
t1
A
B
t2
t3
P1
P2
t'
0
10
20
30
40
50
60
angles [°]

Fig.3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speed %
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80
60
40
20
0
0
10
20
30
40
50
60
angles [°]
q2
t'
t
q1

Fig.4

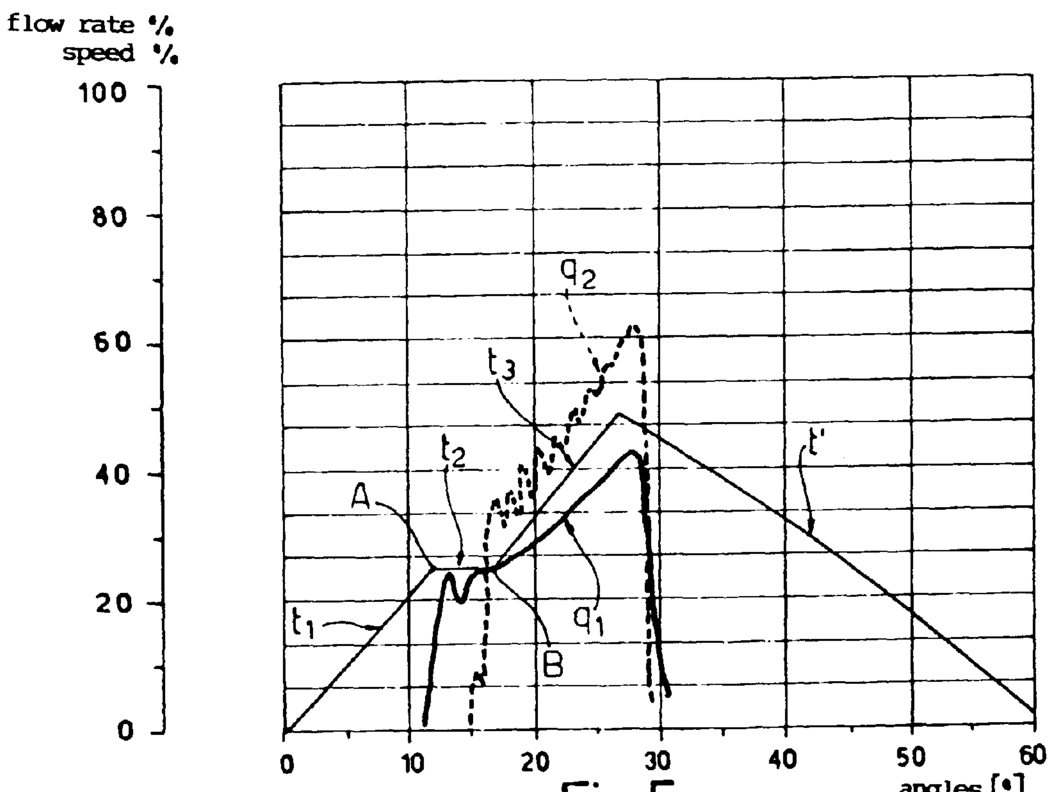
flow rate %
speed %
100
80
60
40
20
0
0
10
20
30
40
50
60
angles [°]
q2
t3
t2
A
t'
t1
q1
B

Fig.5