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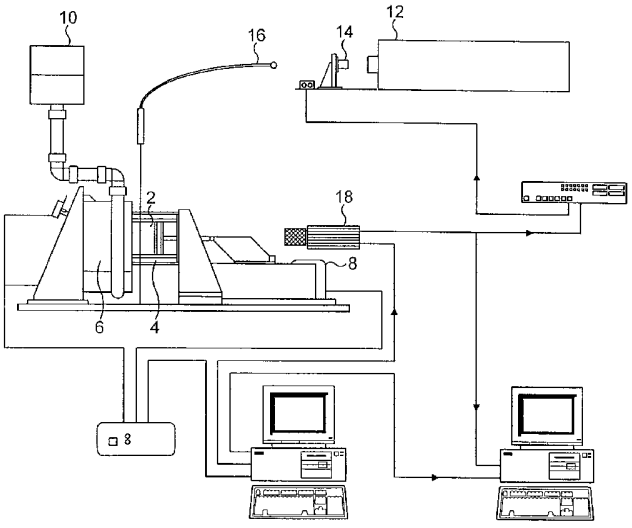
(54) Title: FLOW VISUALISATION



(57) Abstract: A method of visualising the flow in a fluid flow space in an apparatus, such as an internal combustion engine, comprises providing a model (2, 4) of at least that portion of the apparatus which defines the flow space, the model being made of transparent material or including a transparent portion which at least partially defines the flow space, introducing feed particles into a liquid and causing the liquid to flow through the flow space, illuminating the flowing liquid in the flow space and viewing the distribution of the particles. The liquid may comprise a mixture of benzyl alcohol and benzyl benzoate whose refractive index is the same as that of the transparent material, e.g. epoxy or acrylic material. Alternatively, the liquid may be an aqueous solution of sodium benzoate and the transparent material may be silicone rubber.

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FLOW VISUALISATION

The present invention relates to a method of flow visualisation, that is to say a method of visualising and optionally measuring and/or recording the flow pattern of a fluid flowing through a flow space within an apparatus.

Many types of apparatus have a flow space through which, in use, a fluid flows. The precise flow pattern of that flow is frequently of crucial importance, e.g. to the service life or efficiency of the apparatus. However, the walls of the flow space are invariably opaque which means that the actual flow pattern, in use, may not be seen. It is, therefore, known to provide one or more transparent windows in the walls of the flow space in a sample or model of the apparatus or to make a model in transparent material of the relevant portion of the apparatus and then to cause a fluid to flow through the flow space. Upstream of the flow space the fluid is "seeded" with small particles. The fluid flowing within the space is illuminated, typically by a laser, and the flow pattern of the fluid may then be viewed with reference to the position and distribution of the seed particles in the fluid. The flow pattern is normally viewed by means of a camera which records the instantaneous position and distribution of the seed particles and permits them to be viewed and analysed at length at a later time.

One example of apparatus in which the fluid flow pattern is of considerable importance is throttling and shut-off valves for use with high throughputs of water, chemicals or other liquids. Small changes in the design of the valve can have a major effect on the liquid flow pattern and this can in turn have a major effect on the efficiency of the valve and on its service life, particularly when the valve is subject to erosion or corrosion by the liquid flowing through it.

A further important example of apparatus in which the fluid flow pattern is crucial is internal combustion engines. The pattern and intensity of the swirl, tumble or other turbulence in the combustion chamber of such an engine has a crucial impact on the degree of mixing of the fuel and air in the combustion chamber and on the spatial distribution of the fuel at the moment ignition occurs. In order to optimise the design of the engine it is known to make a model of a portion of the engine with one cylinder made of glass and the associated piston made of perspex or polyester. A liquid is then passed into the cylinder whilst reciprocating the piston in order to mimic operation of the engine. Upstream of the cylinder the liquid is seeded with small particles. The moving liquid and seeding particles within the cylinder are illuminated, usually through the side wall of the cylinder, by means of a laser constructed to emit a substantially planar beam of light perpendicular to the cylinder axis. The illuminated particles within the said plane are then viewed and normally photographed and their relative positions and distribution gives an indication of the flow pattern within the cylinder.

One of the most important parameters in an internal combustion engine is the pattern and intensity of swirl of the fuel and air in the combustion space, that is to say rotation of the fuel and air around the cylinder axis. In order that this swirl may be visualised, the swirling liquid and entrained seed particles are illuminated as described above transverse to the cylinder axis and viewed through the piston, which is transparent, because swirl patterns may only be seen properly when viewed in the axial direction. However, the piston is invariably of varying thickness and its refractive index differs from that of the liquid. The difference in refractive index leads to a perceived positional

displacement of certain of the seed particles with respect to others and thus to corruption of the recorded flow pattern.

In order to eliminate problems arising from the difference in refractive index of the glass and the liquid, the cylinder is normally positioned in a glass container fill ed with the same liquid. However, a very limited number of sizes of glass cylinder are commercially available and delivery times are very long. Furthermore, the glass containers tend to leak after a period of storage. The preferred liquid is traditionally water, because it is cheap and has no injurious effects, but its refractive index is so very different to that of glass, perspex and polyester that any flow visualisation results obtained using water are seriously flawed.

Attempts have been made to match the refractive indexes of the material of which the model is made and of the liquid but these have involved either using an inappropriate material for the model or a liquid which is unacceptably toxic, such as a mixture of toluene and diphenyl methane, or unacceptably inflammable, such as a mixture of white spirit and tetralin, or has an unacceptably high variation of refractive index with temperature, or is unacceptably corrosive, such as a solution of potassium thiocyanate in water.

Accordingly, it is the object of the invention to provide a method of flow visualisation of the type described above in which the model may be made from a material which is readily available and may be easily machined so that a model may be rapidly produced and the result is not degraded by differences in refractive index and does not require the use of a liquid which is potentially harmful or in any other way disadvantageous.

According to one aspect of the present invention there is provided a method of visualising the flow, in use, in a fluid flow space in an apparatus which comprises providing a model of at least that portion of the apparatus which defines the flow space, the model being made of transparent material or including a transparent portion which at least partially defines the flow space, introducing seeding particles into a liquid and causing the liquid to flow through the flow space, illuminating the flowing liquid in the flow space and viewing the distribution of the particles, the liquid comprising a mixture of benzyl alcohol and benzyl benzoate. The model or the transparent portion thereof preferably comprises polyester material, e.g. an acrylic, or epoxy resin material, both of which have a high refractive index of between about 1.25 and 1.60.

According to a further aspect of the present invention, the liquid comprises an aqueous solution of sodium benzoate. A suitable material for the model with such a solution is transparent silicone rubber, such as that manufactured by MG Chemicals Limited and sold under the Trade Mark RTV 615.

Thus the method of the present invention is substantially similar to the known method, the crucial difference being the composition of the liquid. The refractive index of a mixture of benzyl alcohol and benzyl benzoate varies between about 1.3 to 1.58, depending on its composition. The refractive index of sodium benzoate solution at a concentration of about 35% by wt. is between 1.40 and 1.41, typically 1.405. The refractive index of the liquid may be adjusted by varying the precise composition of the liquid to be precisely equal to that of the model or its transparent portion. This will result in no relative positional displacement of any of the seed particles and thus in the observed

flow pattern, as indicated by the positions and distribution of these seed particles, corresponding precisely to the actual flow pattern. The mixture of benzyl benzoate and benzyl alcohol and also the aqueous sodium benzoate solution are not toxic or inflammable and nor does their refractive index vary substantially with temperature. Accordingly, the use of these liquids substantially overcomes all the problems referred to above.

The use of polyester epoxy resin material or silicone rubber for the model means that it may be produced rapidly and cheaply because such material may be readily machined.

It is of course important that the seeding particles are inert to and insoluble in the liquid and it is desirable that they also have high reflectivity to enable them to be easily seen. It is also highly desirable that the density of these particles closely, or more preferably, precisely matches that of the liquid, that is to say that the particles have neutral buoyancy, so that they are not displaced by buoyancy forces. It is preferred that the particles comprise titanium dioxide coated with plastic material and nylon has proved to be particularly effective for this purpose. It is preferred that the particles have a diameter in the range of 50μ to 150μ.

The method of the present invention is applicable to a wide range of different types of apparatus but in the preferred embodiment the apparatus is an internal combustion engine and the model comprises a transparent piston movable in a transparent cylinder which communicates with an inlet duct via an inlet valve, the method comprising illuminating the liquid flowing in the cylinder by means of a laser constructed and arranged to emit a substantially planar beam of light

perpendicular or parallel to the axis of the cylinder and viewing the particles in a direction perpendicular to the plane.

It is preferred that the viewing is effected by means of a camera which records the position and distribution of the particles. The camera is preferably arranged to make a plurality of sequential pictures to enable the change in distribution of the particles over time to be visualised.

Further features and details of the invention will be apparent from the following description of one specific embodiment which is given by way of example with reference to the single accompanying drawing which shows a rig for visualising the flow in an internal combustion engine.

The rig includes a model simulating a single cylinder in an internal combustion engine and comprising a transparent piston 2 made of polyester, such as acrylic material, in this case polymethylmethacrylate, or epoxy resin reciprocably mounted in a cylinder 4 formed in a transparent block of similar material. Formed at the end of the cylinder remote from the piston in a cylinder head 6 are an inlet port and an outlet port (not visible). The ports and piston and all other constructional features of the model were made to correspond precisely to those of the engine in which the flow is to be visualised. The piston is connected to be reciprocated by an actuator 8 and the inlet valve was arranged to be opened and closed in synchronism therewith in the conventional manner. Since liquids are substantially incompressible, the timing of the exhaust valve differed from that of a conventional engine. The exhaust valve was arranged to be closed during the entire intake stroke of the piston and open during the exhaust stroke. Alternatively, the exhaust valve may be disabled and the fluid

returned via the inlet valve on the exhaust stroke. Connected to the inlet port was an inlet duct which was in turn connected to a liquid supply reservoir 10. The exhaust port was connected to an exhaust duct arranged to return liquid to the reservoir. Situated close to the cylinder is a laser illumination device 12 of known type, in this case of argon ion type connected via an optical shutter 14 to a fibre optical system 16 constructed to emit a substantially planar beam of light to illuminate a plane within the cylinder. Situated with its viewing direction perpendicular to this plane is a video camera 18 arranged to take a plurality of sequential still pictures at predetermined time intervals. The orientation of the plane is selected in accordance with requirements and will be perpendicular to the axis of the cylinder if swirl of the fluid is to be viewed and parallel to the axis if tumble is to be viewed.

In use, the reservoir was initially filled with a mixture comprising 73% by weight benzyl benzoate and 27% benzyl alcohol. The refractive index of this mixture was then adjusted by selective tuning of the mixing ratio until it precisely corresponded to that of the material of which the cylinder and piston were made. In the case of an acrylic, such as polymethylmethacrylate, this final mixture would have a refractive index of around 1.4893. A large number of seeding particles comprising nylon coated titanium dioxide with a diameter of the order of 100μ was introduced into the reservoir and maintained in a distributed suspended state by means of a stirrer or agitator (not shown).

In use, the piston was reciprocated and induced the liquid with seeding particles entrained therein to flow into the cylinder during the expansion stroke and to flow out through the exhaust valve or the inlet valve, as the case may be, back into the reservoir during the compression stroke. The camera was operated to

take a number of pictures and the position and distribution of the seed particles, as illuminated by the pulsed laser and recorded by the camera, was indicative of the flow pattern and velocities within the cylinder.

CLAIMS

1. A method of visualising the flow in a fluid flow space in an apparatus which comprises providing a model of at least that portion of the apparatus which defines the flow space, the model being made of transparent material or including a transparent portion which at least partially defines the flow space, introducing seed particles into a liquid and causing the liquid to flow through the flow space, illuminating the flowing liquid in the flow space and viewing the distribution of the particles, the liquid comprising a mixture of benzyl alcohol and benzyl benzoate.

2. A method as claimed in claim 1, in which the model or the transparent portion thereof comprises polyester material.

3. A method as claimed in claim 1, in which the model or the transparent portion thereof comprises an epoxy resin material.

4. A method as claimed in claim 1 or 2 in which the model or the transparent portion thereof comprises acrylic material.

5. A method of visualising the flow in a fluid flow space in an apparatus which comprises providing a model of at least that portion of the apparatus which defines the flow space, the model being made of transparent material or including a transparent portion which at least partially defines the flow space, introducing seed particles into a liquid and causing the liquid to flow through the flow space, illuminating the

flowing liquid in the flow space and viewing the distribution of the particles, the liquid comprising an aqueous solution of sodium benzoate.

6. A method as claimed in Claim 6 in which the model or the transparent portion thereof comprises transparent silicone rubber.

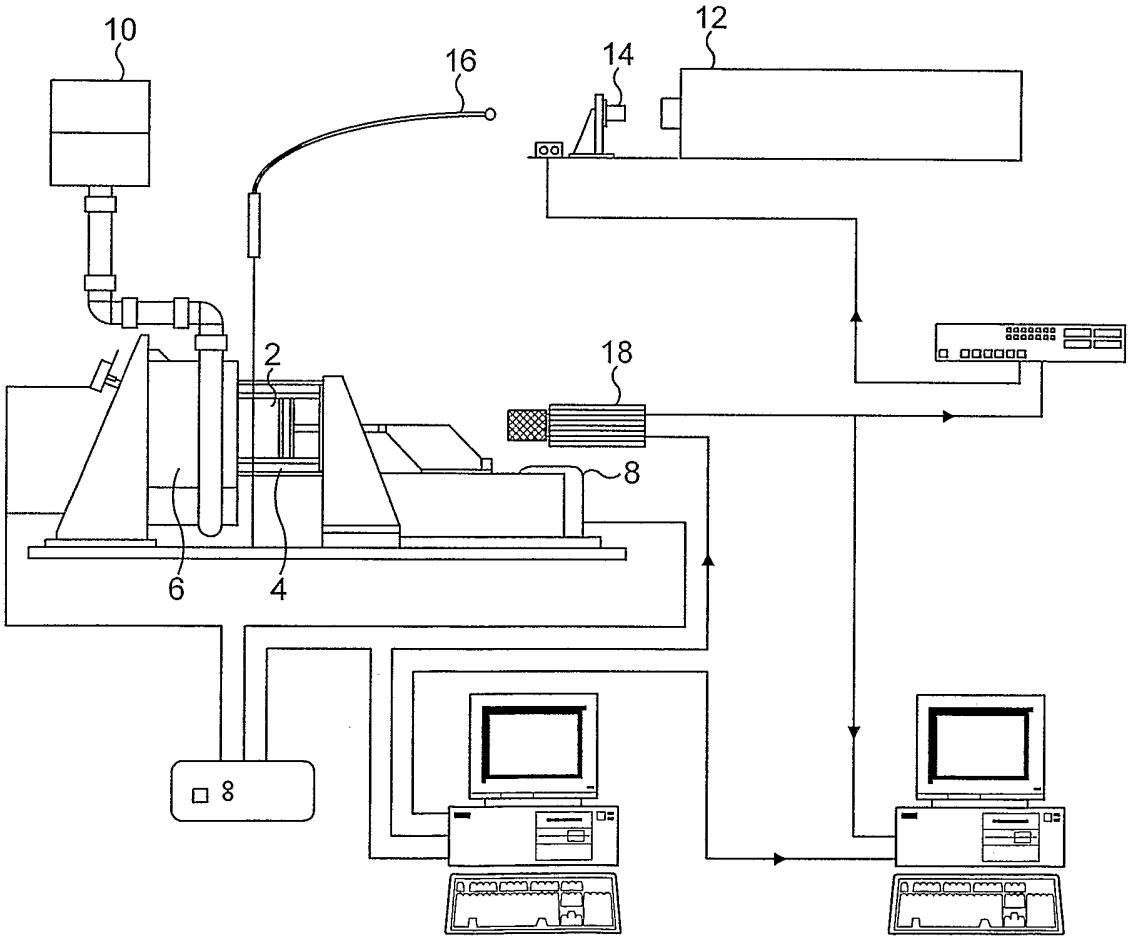
7. A method as claimed in any one of claims 1 to 6 in which the seed particles comprise titanium dioxide coated with plastics material.

8. A method as claimed in any one of the preceding claims in which the seed particles have a diameter of between 50μ and 150μ.

9. A method as claimed in any one of the preceding claims in which the apparatus is an internal combustion engine and the model comprises a transparent piston movable in a transparent cylinder which communicates with an inlet duct via an inlet valve, the method comprising illuminating the liquid flowing in the cylinder by means of a laser constructed and arranged to emit a substantially planar beam of light and viewing the particles through the piston.

10. A method as claimed in any one of the preceding claims in which the viewing is effected by a camera which records the distribution of the particles.

11. A method as claimed in claim 10 in which the camera is arranged to take a plurality of sequential pictures to enable the change in distribution of the particles over time to be visualised.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INTERNATIONAL SEARCH REPORT

Int ɔnal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01P5/00 G01M10/00 G01M9/06 G01P13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01P G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BUDWIG R: "REFRACTIVE INDEX MATCHING METHODS FOR LIQUID FLOW INVESTIGATIONS" EXPERIMENTS IN FLUIDS, SPRINGER VERLAG. BERLIN, DT, vol. 17, no. 5, 1 September 1994 (1994-09-01), pages 350-355, XP000477667 ISSN: 0723-4864 page 350 -page 352; tables 1,2 ---	1,5
A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 348 (P-519), 22 November 1986 (1986-11-22) & JP 61 148340 A (MITSUBISHI HEAVY IND LTD), 7 July 1986 (1986-07-07) abstract ---	1,5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
14 October 2002	23/10/2002

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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