CRANKCASE EXPLOSIONS

BY

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Introduction

The danger of an explosion exists in any enclosed piece of machinery where lubricating oil, mixed with sufficient air may be ignited by a source of heat. Explosions are not confined to oil engines ; cases have been reported of explosions in the crankcases of steam reciprocating engines, compressors and gearcases. The following comments have been restricted, however, to the subject of explosions in compression ignition engines.

It was not until 1947, when a serious explosion occurred in the passenger liner *Reina del Pacifico,* and twenty-eight persons lost their lives, that the danger of crankcase explosions assumed sufficient importance to warrant intensified investigation into the whole subject by research workers in Great Britain. About this time, similar work was also put in hand in the U.S.A. though this was mainly restricted to the protection of certain Diesel engines fitted in the U.S.N. and Diesel locomotives.

The Pattern of Crankcase Explosions

A study of reports indicates that most crankcase explosions follow a general pattern :—

(*a*) A part, such as a piston or a bearing, becomes overheated.

(*b*) This overheated part vaporizes the lubricating oil and this vapour mixes with the air in the crankcase and, under certain conditions, forms a combustible mixture. If the overheated part is hot enough, the mixture will be ignited and, depending on the mixture strength, the ignition source, the shape and size of the crankcase and other factors, the result may be an explosion varying in intensity from a puff of white smoke to a severe explosion resulting in an excessive pressure in the crankcase. The crankcase covers may be blown off allowing burning oil and gas to be forced out through the openings.

(*c*) When the expansion and escape of the gases after the first explosion are completed, there is a contraction of gas in the crankcase tending to draw in more air and thus provide additional oxygen for a possible secondary explosion. In a large number of cases this secondary explosion is responsible for most of the damage.

Investigations have shown that the atmosphere inside a crankcase is not explosive under normal conditions and is not immediately ignitible. The oil is present in the form of a coarse mist with a negligible amount of vapour. The British Internal Combustion Engine Research Association (B.I.C.E.R.A.) in a report (No. 51/2) states that a hot spot at a temperature of 1,200 degrees F. or above is required to ignite the explosive mixture formed by the vaporized oil. Investigations by the Thornton Research Centre (*Inst. Mech. Eng. Proceedings* : 24/4/56) showed that it is possible to ignite an oil vapour and air mixture at much lower temperatures than those quoted by B.I.C.E.R.A. Investigations in the U.S.A. (*A.S.M.E. Trans.* 74 : 1/1/52) gave comparable results to those of B.I.C.E.R.A. and as the Thornton tests were concerned with the mixture passing through small heated tubes whereas the others involved explosion chambers with controlled hot spots, it is generally accepted that the B.I.C.E.R.A. and American results are more appropriate to the conditions in a Diesel engine.

The B.I.C.E.R.A. report states that normal crankcase ventilation cannot be relied upon to maintain a safe atmosphere since the production of the vapour may be too rapid to be cleared satisfactorily. Also, explosions can occur after shut-down if the hot spot remains at a high enough temperature or if an oil fire has started. The likelihood of an explosion is increased by agitation or air injection. If an overheated engine is restarted, an explosion is particularly likely. Pressures attained by the primary explosion are usually of the order of a few pounds per square inch, though, under ideal conditions, pressures up to 100 lb/sq in are possible. Ideal conditions require a thorough mixing of the oil vapour and air which is unlikely in the majority of cases. Detonation is regarded as very unlikely.

Causes of Crankcase Explosions

Examination of a number of reports reveals that crankcase explosions have occurred in all types of Diesel engine, 2-cycle or 4-cycle, stationary, marine and rail traction of 300 h.p. and upwards. Some overheated part such as a seized piston, gudgeon pin, connecting rod or camshaft bearing was considered the source of ignition in the majority of cases. Small auxiliary-drive bearings of gunmetal or lead bronze are particularly troublesome, whereas the white-metal-lined bearing appears to be immune because of the relatively low melting point. One speaker in a Diesel Engineers and Users' Association discussion stated that ignition due to piston seizure is less likely to take place with aluminium alloy pistons than with cast iron pistons, because of the higher heat conductivity and the lower hot strength of the aluminium alloy. Although there is no real evidence to support this, it is noted that in the reports of explosions caused by piston seizures, all the engines are the type normally fitted with C.I. pistons.

It is evident that the probability of a serious explosion occurring depends a lot on the size of the engine. One American investigator suggested that engines with a crankcase volume less than 80 cubic feet are relatively safe. For purposes of comparison, the A.S.R.1 12-cylinder engine has a crankcase volume of about 100 cubic feet. The immunity of the small engine must be due to the relatively stiff crankcase and the general absence of lightly secured inspection doors, the crankcase being capable of containing a primary explosion without breaking up and allowing the entry of air to cause the more severe secondary explosion. Many reports of piston and other failures in the smaller engines have been accompanied by the observation that ' a puff of white smoke was seen issuing from the breather '. This indicates that sufficient heat was produced to vaporize some oil and possibly cause ignition and a slight pressure.

Fuel Dilution

Fuel dilution of the lubricating oil is suspected in a number of cases but tests carried out in the U.S.A. (*A.S.M.E. Trans.*, Jan., 1952) showed that quite high rates of dilution will have no significant effect. The reason or this is that, although dilution causes a sharp drop in flash-point temperature, the auto-genous ignition temperature shows only a gradual decrease, i.e. for a dilution of 20 per cent, the flash-point temperature dropped from 475 degrees F. to 325 degrees F. whereas the ignition temperature decreased from 775 degrees F. to 750 degrees F. Since dilution in excess of 20 per cent is outside the range of practicability, normal fuel dilution should have no significant effect.

Prevention of Explosions

It must be accepted that hot spots are liable in any Diesel engine and so long as inflammable lubricants are employed, a potentially dangerous situation exists. A certain number of preventive measures can be incorporated in the design of an engine : adequate oil ways or pipes, suitable piston ring gaps and piston clearances, etc., but none of these can cater for maloperation or bad maintenance.

Various preventive measures designed either to prevent an explosion or to control it within limits have been investigated and adopted to a varying degree. These can be classed under three headings :—

(*a*) Quenching devices

(*b*) Warning devices

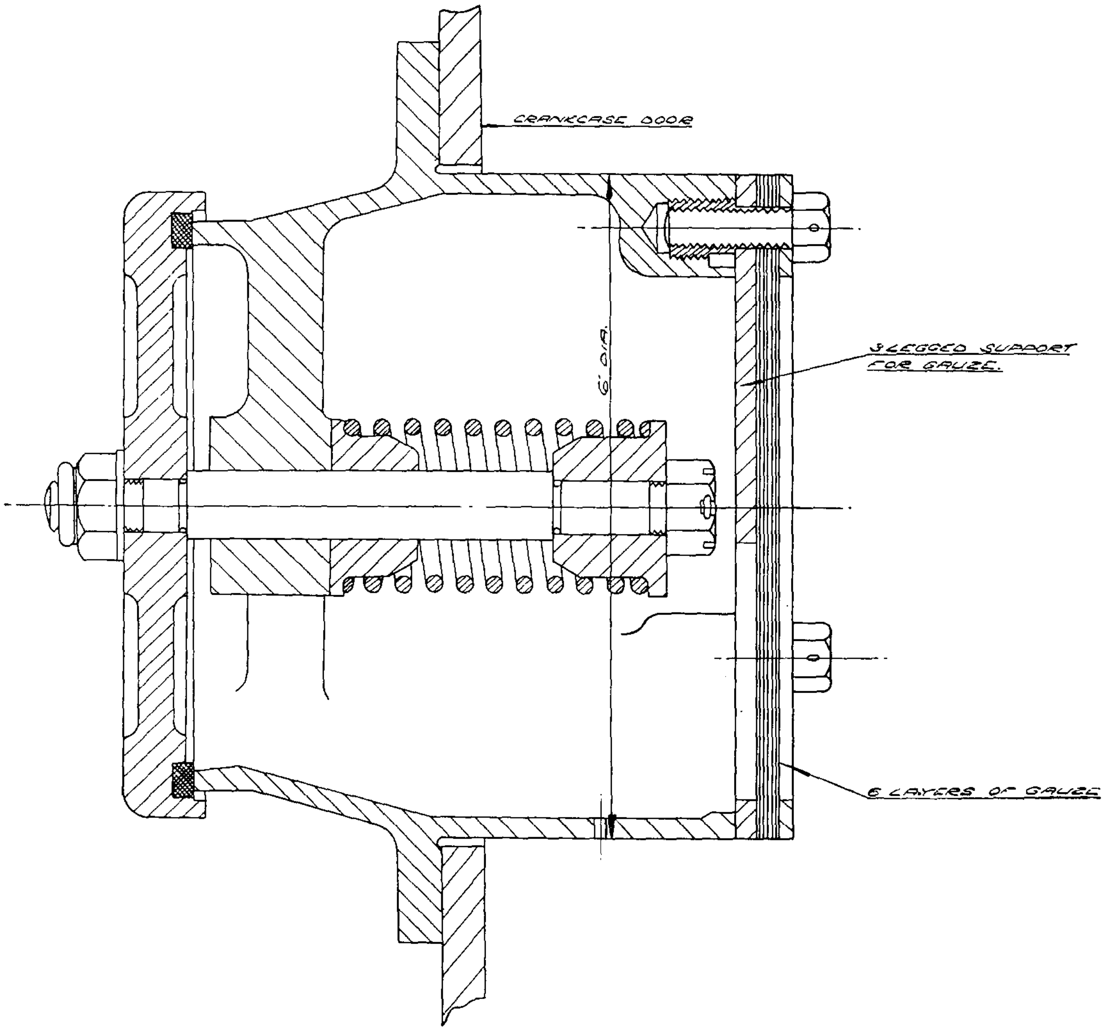
(*c*) Relief devices.

In (*a*), the substitution of an inert gas or exhaust gas for some of the air in the crankcase would prevent ignition provided the maximum oxygen concentration in the crankcase was below 12 per cent. Carbon dioxide (and possibly nitrogen) have been suggested but in view of the mechanical difficulties involved in permanently sealing the crankcase, and the cost of the gas, its use has never passed the experimental stage. Except at full load, it would be of little use to utilize the engine's own exhaust to scavenge the crankcase because too much oxygen would be present. The exhaust from a small auxiliary Diesel engine could be used, but it would be necessary to clean and filter the gas to avoid contaminating the lubricating oil of the larger engine and it is because of this, and the need for the auxiliary engine, that this method of protection has not been considered.

With regard to (*b*), the initial filling of the crankcase with an inert gas and maintaining a sufficiently high concentration is a certain deterrent but, as stated above, is difficult to apply and can be expensive. An alternative method is to maintain a supply of gas in storage bottles for release into the crankcase when there is some sign of overheating and the simplest arrangement would be to leave the admission of the gas to the operator because, in the majority of cases, prior warning is received. This, however, relies on the vigilance of the operator and his willingness to use the device. Alternatively, the system may be operated automatically following the development of an abnormally high temperature or of an oil mist in the crankcase. The high temperature warning would consist of thermocouples or similar temperature-sensitive devices placed at likely positions—bottom of cylinder liners, main bearings, etc. However, as it is not practicable to have a warning device at every position likely to form a hot spot, the advantages of this system are limited.

The oil mist method of detection consists of a detector which responds to an oil mist of a density varying between about one to ten per cent of the lower explosive limit. Basically, it consists of a spotlight projecting a beam of light on to a photo-electric cell and when obscurity by the mist reaches a predetermined level, the reduction in output from the photo-electric cell operates an alarm or a gas injection unit. This type of equipment has been installed on large slow-running engines of the Doxford type but is unsuitable on the smaller, higher speed, naval trunk-type piston engines because of the large quantities of lubricating oil being thrown about in the crankcase.

In the case of relief devices (*c*), tests carried out in this country (B.I.C.E.R.A., British Shipbuilding Research Association (B.S.R.A.), etc.) and in the U.S.A. have shown that, by the use of a suitable design of relief valve, it is possible to limit the maximum pressure of a crankcase explosion to that which the crankcase can withstand.



ARRANGEMENT OF EXPLOSION RELIEF VALVE AND FLAME TRAP FOR A.S.R.1 ENGINE

These valves, being easy to fit, are the most used safeguard. To be suitable, a valve must relieve the pressure as rapidly as possible and, to do this, must be light and not too heavily spring-loaded. It should also close quickly, making an airtight seal to prevent the ingress of air and the possibility of a secondary explosion. The valves should be numerous and preferably fitted to each crankpit. Various recommendations have been made as to the area of relief valves ; the U.S.N. specify 1·5 square inches per cubic foot of crankcase volume, the American Bureau of Shipping 0·5 square inches and *Lloyd's Register of Shipping* approximately 1·0 square inch per cubic foot. One objection to relief valves is the difficulty of keeping them oil tight because of the light spring pressures involved. To overcome this some engine makers fit a thin joint or gasket over the valve opening, so arranged that this joint is perforated when the valve operates. Care is necessary in the choice of jointing material, as quite a number of reports on crankcase explosions state that the thin cardboard relief discs did not burst but the crankcase doors did.

The discharge of hot explosion gases and burning oil from plain relief valves can be a grave danger to personnel and a number of deaths and injury from this cause have been reported. B.I.C.E.R.A. have investigated this and found that the addition of a flame-trap consisting of a number of layers of gauze can be very effective in suppressing flame, provided the gauze is coated with lubricating oil. The ideal position for the flame-trap in the trunk-piston type engine is inside the crankcase where it will be continuously soaked with the oil splashed about in the crankcase. On the slow running crosshead type engine, it is usual to fit the flame-traps inside with a special supply from the lubricating oil system to keep them soaked.

An arrangement of a relief valve combined with a flame-trap for fitting on a 12-cylinder A.S.R.1 engine for an Ocean Class tug is shown in the illustration. The design is based on B.I.C.E.R.A.'s recommendations, meets Lloyd's requirements and one will be fitted to each crankpit. B.I.C.E.R.A. and B.S.R.A. investigations have also shown that the intensity of a primary explosion is reduced if oil-wetted flame-traps are fitted over the apertures in the divisions between adjacent crankpits. These restrict an explosion to the affected crankpit. It is essential that the flame-traps are a very close fit round the bearing housing, etc., as a gap of 0·10 inch is sufficient to permit the passage of flame. They are difficult to fit on the smaller engines and, provided the crankcases are strong and have large enough relief valves, they are usually omitted on the trunk-piston type engines.

The Ministry of Transport recommend relief valves or doors on all engines of more than about 500 b.h.p. whereas the American Bureau of Shipping require them on engines over 8-inch bore and *Lloyd's Register of Shipping* on engines of 6-inch bore and over.

Installation Requirements

A review of the reports dealing with crankcase explosions emphasizes the danger of interconnecting engine crankcases by ventilating systems, common sump tanks or other open piping systems. Pipes permanently full of oil appear to be quite safe.

Watchkeepers should not normally be stationed at the side of an engine, either end being much safer for the control position.

Security Measures when Trouble is Experienced.

The Ministry of Transport have issued a directive to marine engine builders, shipowners and shipbuilders on the subject of crankcase explosions and in this include certain instructions for the guidance of engineers on precautions to be taken. These are :—

(i) Early detection of overheating and as prompt a reduction of engine revolutions as circumstances will permit. This will prevent the occurrence of conditions favourable to an explosion.

(ii) Crankcase and inspection doors should not be opened, and the engine should not be restarted, until it has cooled down.

(iii) Oil should not be sprayed on any surface the temperature of which is above blue heat (about 550 degrees F.) as fire risk is caused thereby.

Regarding (ii) above, the American Bureau of Shipping recommends at least ten minutes wait before removal of crankcase doors.

Conclusions

Considering the number of Diesel engines in service, the incidence of crankcase explosions is remarkably low but reports show that when an explosion does occur on an unprotected engine, it can be very severe. The severity of the explosion increases with the size of the crankcase ; this is logical in that most explosions are set off by hot spots located near the top of the crankcase and the larger the crankcase, the larger the pocket of air-oil vapour mixture that may be formed at the top of an individual crank section.

The number of reported cases of explosions in the Navy are very small : the Author has knowledge of four during the past seven years. This must be because the majority of naval engines are 7-inch bore and below and are of the high-speed type with fairly robust crankcases. Submarine engines are relatively free from this trouble and only one case is known to the Author. This is probably accounted for by the high standard of maintenance and watchkeeping, and to the fact that, where piston seizure has occurred, the pistons have been of aluminium.

Certain precautions can be taken to reduce the possibilities of explosion and to avoid injury to personnel in the event of an explosion. These are :—

(*a*) *Care in refitting.* A high proportion of the incidents associated with pistons and bronze or gunmetal bearings occurred after repairs and were due to incorrect clearances, blockage of lubricating oil supplies and, in the case of bearings, to the use of incorrect material (too soft) for the shafts.

(*b*) *Positive form of securing crankcase inspection doors.* The friction-held type of crankcase door is often a poor fit and some positive form of securing them is desirable.

(*c*) *Ministry of Transport instructions.* These are very sound and will be embodied in the next reprint of *B.R.* 16.

The question of fitting relief valves to the various types of engines in the Service is under consideration.