VALVE SPRING FAILURE*

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Over a period of some years before the war the valve springs of submarine engines were a more or less constant source of anxiety on account of the epidemics of failures which occurred with unpleasant frequency and which no expedient of design seemed able to cure.

The first thought when a new design of spring started to suffer from failures was that the stresses should be reduced and this action would generally be found to lead to increased life, but never to immunity from failure, even when the stresses had been reduced to very low levels as compared with the valve springs of, say, motor car engines which rarely suffer spring failures.

Another possibility which came into prominence was that the springs were being subjected to appreciably higher stresses than those contemplated in the design ; this idea originated in the observation that most failures took place near the bottom end of the spring, a characteristic of failures due to " surging " which brings the stresses up to higher levels than when the spring operates normally. Modifications of design to eliminate the possibility of marked surging failed to obviate failures.

Effect of Surface Layers

Attention was then turned to the question of material ; the manufacturers of aero engines had found that in their highly stressed springs the condition of the surface layers of material was of the greatest importance. Apart from such obvious steps as avoiding deep scratches and cracks in the surface of the wire they had found that reduction of the carbon content in the surface layers of the steel wire (surface decarburisation) was a serious source of weakness. All steel articles which have undergone a fair amount of hot working during their fabrication from the original ingot and which have not been machined after this hot working, show a layer of greater or less depth in which the carbon content of the material, and consequently its hardness, is considerably less than in the material as a whole. When one considers that in a valve spring the stresses are at a maximum at the surface of the wire it will be appreciated that the presence of this layer of low strength at the position of maximum stress is likely to be a prolific cause of failure. To make matters worse, there is always the possibility that during the hot working operations necessary in reducing the original ingot to the form of wire rod, particles of scale will be rolled into the surface and these particles will, in the finished wire, act as stress raisers. For many years now all the wire used for aero engine valve springs has been ground at a late stage in fabrication, after all hot working and high temperature heating operations, to an extent sufficient to remove all the decarburised layer and rolled in scale.

Examination of a number of failed valve springs from submarine engines showed that the wire from which they had been made was heavily decarburised at the surface and also that, in some instances, there were large particles of scale

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embedded in the surface. It seemed, then that the principal cause of failures had been located and that the cure of the troubles was to lie in obtaining wire from which all this defective surface layer had been removed. In practice it did not prove easy to obtain wire of the large gauge used for the valve springs of submarine engines with the decarburised layer removed; equipment for grinding the wire at the appropriate stage of manufacture was not available and progress towards procuring supplies of good quality wire was slow. In the meantime alternative designs using wire of smaller diameter which could be obtained free from surface defects were tried out, and it seemed that the problem could be solved in one way or another.

Laboratory tests

It was at this stage, when a solution seemed in sight, that an observation was made which caused some uneasiness of mind to the protagonists of surface decarburisation as a cause of the failures which had been experienced and of good quality wire as a cure for the troubles. Some failed springs from a small engine were received for examination and were found to be of excellent quality material ; further, the springs were not particularly highly stressed, yet they had failed after a comparatively short life in service. It was noted that the springs were somewhat corroded and it was thought possible that corrosion pits in the surface resulting from storage under bad conditions had led to the failure.

About this time one of the Dockyards obtained a large batch of springs for one type of submarine engine and being, from a cause which has never been clear, suspicious of the quality of wire used sent one or two sample springs for inspection. These springs were found to be as extreme a case of surface decarburisation as had been encountered, the effect being present throughout a layer some 0.015 in. deep. These springs seemed excellent material on which to demonstrate the bad effect of decarburisation and a cylinder head was rigged up to take four of the springs and to subject them to the normal deflections at the usual operating speed. The protagonists of decarburisation as the explanation of failures sat back happily anticipating that all four springs would fail in a very short time. When the test carried on to 1,000 hours with no failures their equanimity was disturbed and when 2,000 hours' running had produced no failures they had sadly to admit that their explanation of the failures was not so good as they had thought.

The position then to be faced was that springs made from very poor material were not broken in 2,000 hours' operation in the laboratory, while springs of the same design and generally in better material quite frequently failed in little more than 100 hours running in service, and this at once raised a question as to what were the outstanding differences between the laboratory test and service conditions. The most notable differences seemed to be those of temperature and atmosphere ; the head used in the laboratory tests was operated by connecting the camshaft to an electric motor and the springs were at room temperature all the time, while in service the springs become heated, though so far as was known the temperature they were likely to reach was not such as would notably affect their resistance to cyclic stressing.

Effect of sea water

On the question of the atmosphere there seemed more scope ; it is well known that a corrosive atmosphere, even though very mild, can have a great effect in reducing the resistance of materials to cyclic stressing and it was thought that the difference between the inland atmosphere of the laboratory and the sea water laden atmosphere encountered in marine service might be enough to account for the discrepancy between laboratory test and actual service results. This was soon checked by injecting a small amount of sea water spray at intervals into the vicinity of the springs in the laboratory testing rig ; springs similar to those which had withstood 2,000 hours in the normal laboratory atmosphere now failed in about 100 hours and in a manner very similar to service failures.

Once this suggestion that the atmosphere was an important feature in the failures had been put forward, confirmation of the opinion was forthcoming in the experience of engine builders making identical or closely similar engines for both land and marine service ; engines in which valve spring failures were practically unknown on land were suffering severe epidemics of failures as soon as they were sent to sea, and every attention to the quality of the valve springs appeared to be unavailing.

It appeared then, that if the valve springs could be protected from the corrosive effects of a marine atmosphere their life would be greatly improved, and the problem requiring solution was how to afford this protection. The history of one or two types of engine in marine service suggested that adequate protection could be given by design, but to re-design all engines for this purpose was, evidently impracticable and an investigation was set on foot to find coatings for springs which would protect them satisfactorily against corrosion, be hard enough to stand normal handling, flexible enough not to flake off the spring and which would not be damaged by hot lubricating oil.

Protective coatings

Large numbers of possible coatings were tried in an accelerated form of test employing a high stress range and spraying the springs for 45 seconds once an hour with sea water, conditions under which the design of spring used would fail in 12 to 20 hours when not protected. Of all the coatings tried the the best, from all round considerations, was sprayed zinc about 0.003 in. thick and followed by a coating of an air drying varnish. A coating of sprayed lead was better than the zinc from the corrosion prevention point of view, but was so soft as to be rather readily damaged in handling.

Springs coated in the manner indicated have now been fitted in large numbers to engines of several types and, so far as is known, are behaving satisfactorily—at least no failed ones have come home to roost as yet.

A curious feature, not yet explained, is that whether zinc or lead be used as the protecting metal, it is more effective in the sprayed form than in any other form. The next most effective form is that of being applied by dipping the wire in the molten metal at some late state of wire drawing and then continuing drawing of the coated wire down to final size. In the electrodeposited form on the finished spring, zinc seems to be singularly ineffective, while electrodeposited lead is erratic, most test results being poor while occasional ones are extremely good.