DIESEL ENGINES

FOR

LOW-MAGNETIC SIGNATURE APPLICATIONS IN MCM VESSELS

BY

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Introduction

The research and development associated with low-magnetic signature diesel engines fitted in H.M.S. *Brecon* was described by Commander Gibson in the December 1981 edition of the *Journal of Naval Engineering*.

This article considers the possible methods of achieving low-magnetic signature engines and the present intention for the single-role minehunter (SRMH).

Need for Low-magnetic Equipment

Magnetic mines are designed to be actuated by the degree and rate of change in magnetic field that is generated by a ship moving through the water. Allowance must therefore be made for those regular and occasional variations in the Earth's field which happen on a daily cycle. The total field strength in British waters is 45 000γ and, whilst a steel ship would be expected to generate a field variation of 1500 to 2000γ, the HUNT Class target was expressed as a very much smaller figure. This target was made up of the following components:

(*a*) *Ferro-magnetism*—This can be expressed as an average permeability by calculation of the size of the ship and volume of air displaced by all its onboard equipment. For the HUNT Class, DG Ships specification DG12b provides useful guidance to equipment manufacturers to enable them to meet this requirement.

(*b*) *Eddy Currents*—The movement of metallic materials in the Earth's field due to a ship rolling or pitching will give rise to eddy currents which produce an induced field.

(*c*) *Stray Electromagnetic Field*—Electrical machines have an associated stray field and compensating coils may be fitted to affect this.

The above plus a figure for contingency were used to calculate an overall target figure, and the ship range results of H.M.S. *Brecon* were found to bear a reasonable relationship with the mathematical model predictions.

The design of a diesel engine will result in the particular permeability and hence ferro-magnetism associated with that engine. The means by which ferro-magnetism can be reduced are now considered.

Diesel Engine Design Implications

Ferro-magnetism is made up of permanent magnetism and induced magnetism. The former is inherent in the item whereas the latter is induced by reason of the surrounding field.

When ranging an equipment to determine its magnetic signature, the permanent and induced figures are measured separately in three axes. The results are stated at the distance from the equipment that the measurements are made since the field intensity is proportional to the square of that distance.

Having expressed an average permeability target, the most obvious approach for the diesel designer is to change components as necessary to achieve the required permeability. Were such an engine produced, its signature would not be sensitive to time or geographical magnetic variations. Apart from such stability it would also be independent of any additional parts or external power source. The highly-stressed components of a standard diesel engine are unlikely to have a low permeability and whilst alternative materials do exist they inevitably cost a lot more and a reduction in life and reliability may have to be accepted.

An alternative approach is to accept standard components and demagnetize them by placing them in a strong low-frequency magnetic field. The component is passed through a coil in all three axes, and the lower the frequency and stronger the field the greater the skin effect is overcome. The magnetic stability of this method has yet to be assessed over a long period but results to date appear to be promising. Although production costs increase, the overall increase compared with a standard engine is much less than the change of materials approach and life and reliability are not affected.

The addition of compensation coils will reduce a magnetic field to a predetermined amount. They do increase cost and may inhibit maintenance; also damage to the coils will affect the magnetic signature.

Dipoling is yet another option but individual calibration of components is necessary and the end result is affected by shock, vibration, time, and temperature. Current MOD(N) policy is not to fit dipoles since they limit the theatre of operation and if dislodged the magnetic signature is degraded.

The above is summarized in TABLE I.

TABLE I—*Possible methods of reducing magnetic signature*

Method	*Effect on permanent magnetism*	*Effect on induced magnetism*	*Comments*
Reduce ferro-magnetic content by change of material	Reduction	Reduction	Expensive. Results in non-standard parts. Reliability and life may be reduced. Stable solution
Fit dipoles	Reduction	Reduction	May enable degradation to occur deliberately or inadvertently. Requires calculation for each component. Limitations geographically.
Demagnetize	Reduction		Requires production control and hygienic storage. May not be stable with time
Fit compensation coils	Reduction	Reduction	Additional expense. May inhibit maintenance. Liable to damage which would degrade signature. Allows flexibility in deciding eventual signature

Hunt Class Equipment

The choice of diesel engines and subsequent testing was aimed at providing engines with a low-magnetic signature by virtue of its component material producing a low permeability. Coil compensation and the introduction of demagnetization of components have also been used. The main changes in components to the diesel engines were as follows:

FD12—The Foden engines were particularly suitable for development because of their aluminium crankcase. At the time of commissioning *Brecon* the engines included a change in material in non-risk components, crankshafts, con rods and gearing. A change of liner material had been evaluated and was introduced into the Rolls-Royce build following the take-over by Rolls-Royce of the MCMV contract. The evaluation of pistons and cylinder heads have continued until completion although the ship range results were such that the introduction of these changes will not now take place. TABLE II shows the type of reduction in signature which is obtained with such changes. A price has been paid, however, and the current cost of the MCMV engine is twice that of the standard build. No significant problems in service have been experienced with these changed materials although the liner life is 6000 hours instead of 8000 with the standard material.

TABLE II—*FD12: Engine magnetic signature results*

Engine Build	*Vertical component of magnetism 10^{-5} oersteds*	
	Permanent	*Induced*
1. Standard Engine	42	59
2. MCMV Foden build Mod. state zero	23	28
3. MCMV R-R Motors build plus min. mag. parts (Mods. 3 & 4) min. mag. liners (Mod. 5)	7	21
4. As for 3 plus min. mag. pistons	5	17

Note: Mod. 3 Change of engine fastenings to minimum magnetic material.
Mod. 4 Change of engine components to minimum magnetic material where no technical risk is involved.
Mod. 5 Change of engine liners to minimum magnetic material.

Deltic 59K and 55B—A critical survey was carried out to establish those components that were the major contributors to the overall engine signature. As a result, a material development contract was placed with Napiers in 1964 for the development of non-magnetic crankshafts, con rods, cam shafts, liners, and gears. With the exception of con rods (not considered to be necessary to fit following ship range results), MCMV engines are now so fitted with these components. This has not, however, been without running problems and a high failure rate of engines on production test due to piston scuffing and seizure has resulted in the decision to revert from min mag liners (A286) to standard liners. As an example of cost increase with 'min-mag' material, the standard liners cost £12k per set compared with £31k for the A286 'min-mag' liners. Also there has been a crankshaft failure and this is currently under investigation by Paxman to establish if the fatigue life is satisfactory.

The effect of shock on the magnetic signature of the Deltic engines will be assessed by ranging prior to and after engine shock tests to be held in 1983. The long term stability of engine signature will be measured on nominated Deltic engines where components have been individually ranged prior to build. Such components will again be ranged when these engines are removed for overhaul.

Relative to other solutions (for example the German approach with Motoren und Turbinen-Union (MTU), Friedrichshafen, engines),*Brecon*, for its size, has a much lower signature than any other MCMV in service with the Western Allies. In retrospect the decision to change materials to achieve low-magnetic diesel engines was probably not the most cost-effective approach and the experience gained lends emphasis to the need to re-assess the alternative methods by which low-magnetic engines can be obtained.

In order to assess the magnetic signature achieved by MTU engines, an engine was purchased in 1982 and installed at NGTE (West Drayton). The engine purchased for trials was the 6V396TB83 and this engine was ranged in Germany and again at NGTE Ditton Park. These results compare favourably with each other and a further ranging will be carried out at the end of an engine endurance test to establish if any changes in magnetism have occurred. The MTU 396 magnetically-reduced engines came into service in 1982 and MTU have been asked to provide evidence of magnetic stability over in-service life.

Trials with MTU

The MTU approach is to use standard engines whose components are de-magnetized to reduce the permanent field. This process is carried out by placing the components in an alternating field and subjecting them to that field in all three axes. It is carried out under automatic control and measurements are made after de-magnetization so that the process can be repeated if necessary. The induced component is compensated in the longitudinal and athwartships axes by the ship's degaussing system. The induced vertical field in compensated by four dipoles fitted at the top of the engine and one on the gearbox. Moving the ship from Northern waters to, for example, the equator would of course result in the dipoles having to be repositioned. 90 per cent. of ferrous materials used in highly mechanical-stressed applications are also magnetically hard with a high coercivity, i.e. stable and not easily affected by time, temperature, or vibration. Successful demagnetization therefore means that subsequent changes in the magnetic environment have to be high before they overcome the coercive force and cause a change in a component.

Intentions for Single Role Minehunter

The magnetic target for the SRMH is still within the NATO MCMV target but represents a sixfold relaxation compared with the HUNT Class. This has enabled standard engines to be considered and it has been found that those considered will achieve the target given that ferrous components are de-magnetized and compensation coils fitted. It is intended that demagnetization will be carried out with a lower frequency and higher power than is currently the practice for MCMV equipment and a suitable machine is being sought. With a frequency of 5 Hz instead of 50 Hz and the use of 250 oersteds the penetration will be three times as great as is the case for MCMV demagnetized items. The only changes of material will be for non-risk components which should lead to little increase in cost. Care must be taken of course in assessing standard engines since the permanent magnetism will depend on the magnetic history and the sample ranged may not therefore be representative of what can be achieved in a controlled production run. A similar specification to DG12b will be provided for the SRMH.

Future Policy

In the 1950s attempts were made to construct a model which would enable a resulting change in signature to be calculated from a change in material and permeability. However, the interactive effect within equipments prevented the achievement of a valid model at that time. A contract has been recently placed with a specialist contractor to carry out a survey of the possible method of achieving low-magnetic signature, i.e. change of material, demagnetization, dipole and coil compensation. This survey is aimed at establishing the most cost-effective approach taking into account the required target level, penalities for reliability and life, geographical limitations, etc. Hopefully, the eventual outcome would also be results which could lead to the construction of a mathematical model which could predict the contribution of any one component to the total magnetic influence. Whilst this survey is being carried out on diesel engines as likely to present the most difficult problems, the result should provide useful guidelines appropriate for decision making in the design of other equipments such as hydraulic pumps and motors.

The imposition of a low-magnetic signature for certain diesel engine applications is likely to remain, and the experience with MCMV equipment over the next few years will provide much of the evidence on which future policy will be decided.