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SUMMARY

Support is requested from the Science Research Council for an extension of the research facilities available for the investigation of flexural vibrations of crankshafts at the Advanced School of Automobile Engineering.

Sufficient evidence exists to indicate that flexural vibrations of crankshafts are significant at certain running conditions and critical speeds of an engine. It is also possible that unaccountable failures of crankshafts in service may be explained by fatique as a consequence of large vibrating stresses due to resonance of the bending mode. Lack of knowledge of these vibrations is such that the criteria used for the design of devices that reduce the amplitudes of vibration and noise at the critical speeds are not well founded.

The results of the theoretical and experimental studies already carried out at the school are promising but they are restricted to a particular crankshaft. To fully establish the methods of analysis, to extend the analyses and to test a significant number of crankshafts of various types, it is the proposal that a Senior Research Fellow and a Research Engineer will be employed for three years. Additional test facilities and instrumentation are requested for the extension of the work in progress.

INTRODUCTION

Starting in 1962 a number of investigations into the dynamic behaviour of engine crankshafts have been carried out at the Advanced School of Automobile Engineering, Cranfield. The work has now reached the stage where the rate of progress needs to be accelerated so that the delay in the conveyance of important conclusions to the manufacturers * of reciprocating engines is minimised. It is for this reason that the proposals in this note are put forward.

It is well known that existing knowledge of the flexural * vibrations of crankshafts is inadequate to the needs of the engine designer. For example, it is known that strongly excited bending vibrations are prone to cause noise so severe that the power and economy of the engine are * restricted or special devices are required to be fitted. The design of these devices tends to be arbitrary because suitable criteria are not available.

Because the first and second mode of flexural vibrations are at frequences of the same order as those of the torsional mode, it is reasonable to expect that they will be strongly excited at critical speeds of the engine. The coupling between the flexural, axial and torsional modes is so that the vibrational amplitudes are likely to be particularly large when similar frequencies are exhibited by two modes. Not only will noise tend to be excessive at the critical speeds but excessive large vibratory stresses may occur as a consequence of the combinations of shear and direct stresses due to torsion and bending. Present design procedures tend to underestimate the stress component due to bending.

The aim is to improve the knowledge of the flexural vibrations of a crankshaft so that the critical engine speeds can be predicted with reasonable accuracy for all modes of vibration. With a fundamental knowledge of the problem it will then be possible to rationalise the design of special damping and detuning devices or to optimise the crankshaft system so that the vibratory stresses and noise are minima. Although the investigation is primarily concerned with automobile engines, it is the expectance that the methods of analysis will be applicable to all classes of reciprocating engines.

It is not the intention that the present work should attempt to cover the prediction of the amplitudes of vibration in the flexural mode. This is a problem that can only be considered when a better understanding of the coupling between the modes and the system damping is available.

Previous Work and Work in Progress

Work on the dynamic behaviour of engine crankshafts has been in progress at the School since 1962. By the use of rig and engine tests the knowledge of how the crankshaft behaves as a structure has been improved. Recent work and the work in progress are concerned with the application of this knowledge to the prediction of the natural frequencies of vibration when the crankshaft vibrates primarily in the flexural mode. Because the flexural mode is coupled with the axial and torsional modes, the theoretical approach incorporates the main modes of vibration.

The first investigation (1)* was concerned with the instrumentation of an engine so that the motion of the crankshaft main journals could be observed when the engine was operated over a range of speeds and loads. By the use of two displacement transducers at right angles to each other in a plane perpendicular to the axis of the shaft, a two dimensional locus of the journal centre is provided. Alternatively, the dynamic behaviour of the shaft journal in directions mutually perpendicular to each other may be observed and analysed.

In order to understand clearly the structure of a crankshaft, the experimental results from rigs designed to measure the static stiffness in bending and torsion were compared with theoretical analyses. By the use of a structural model based upon the indications of the static tests, a comprehensive series of tests were followed to find how the dynamic loads due to gas pressure and inertia forces are transmitted to the engine main bearings. Although a treatment of the difficult problem of the effect of bearing constraints is not yet available, by theoretical and experimental work it was possible to arrive at conclusions (2, 3, 6) that assist the engine designer with his assessment of engine bearing loads and crankshaft bending moments.

Sufficient knowledge of the crankshaft structure was now available to justify an approach to the problem of crankshaft resonances. Before the complex structure and distribution of the masses were considered, however, it was necessary to ascertain whether the gyroscopic moments

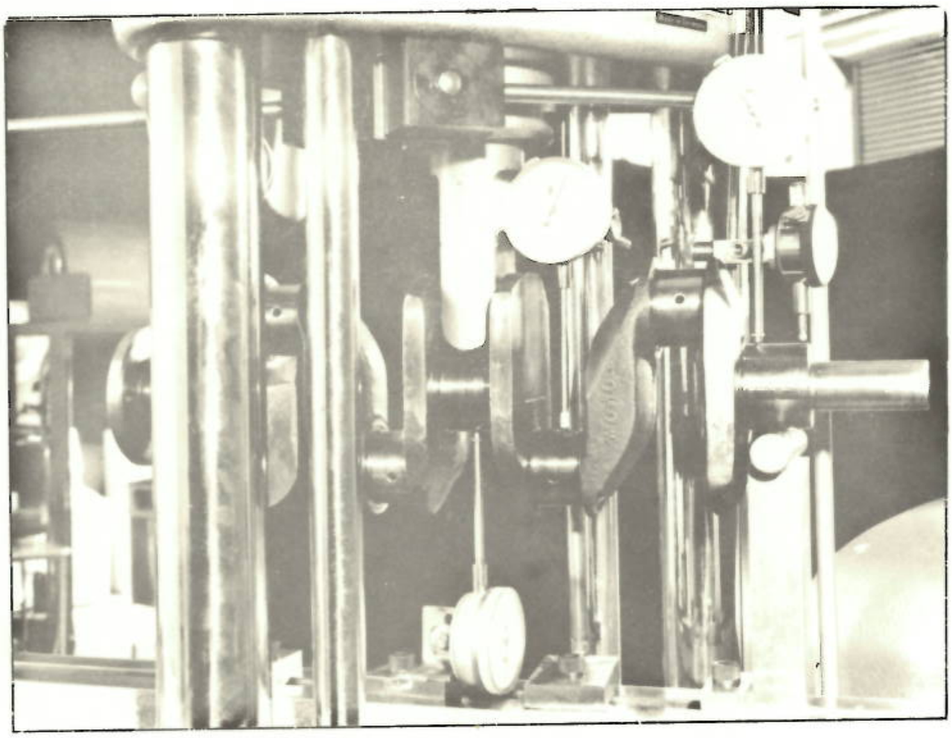
* Figures in parentheses refer to references

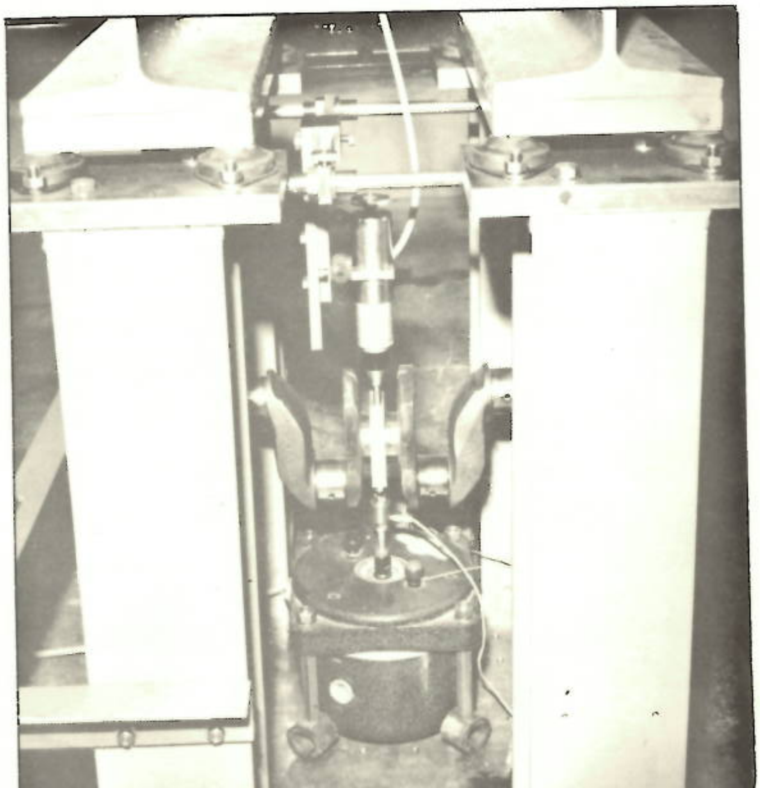
due to the combined rotation and vibration of the engine masses are of any appreciable significance at high operating speeds. A theoretical analysis (5) suggests that for typical multi-cylinder automobile engines, the effects of gyroscopic couples on the frequency of flexural vibrations is small - a reduction of less than 5 percent at speeds up to 10,000 rpm - and can reasonably be ignored by preliminary analyses.

The first theoretical analysis of the flexural mode was restricted to the free-free vibrations of a conventional four throw crankshaft with the crankthrows in the plane of vibration. A rig was designed to minimise the affect of extraneous resonances of a simple structure that supports the crankshaft on a low stiffness elastic suspension. By the use of an electromagnetic vibrator and suitable instrumentation, the resonant frequencies were accurately measured for the first three modes of vibration in the plane of bending and compared with a theoretical evaluation which is programmed for a digital computer. Although the present discrepancy between the theoretical and experimental results is about 7 percent, with an improvement of the theoretical model used for analysis it is expected that the error will be reduced to about half this value.

Two A.S.A.E. students are currently following research into crankshaft vibrations for partial satisfaction of the requirements for the post-graduate diploma, D.Au.E. The intention of their programme, which is restricted to a four-throw crankshaft, is to improve the accuracy of the analysis, to extend the analyses to vibrations in a plane perpendicular to the plane of throws, and to determine the effect of bearing constraints when the crankshaft is rotating at normal operating speeds.

A rig has been designed to allow the excitation of bending vibrations of the crankshaft when it its driven by an electric motor through a flexible drive. The engine that was previously instrumented for the motion of crankshaft journals is to be used for tests under operating conditions.





CRANKSHAFT DEFLECTION MEASUREMENT

TEST RIG FOR FREE-FREE VIBRATION OF CRANKSHAFTS

Proposals

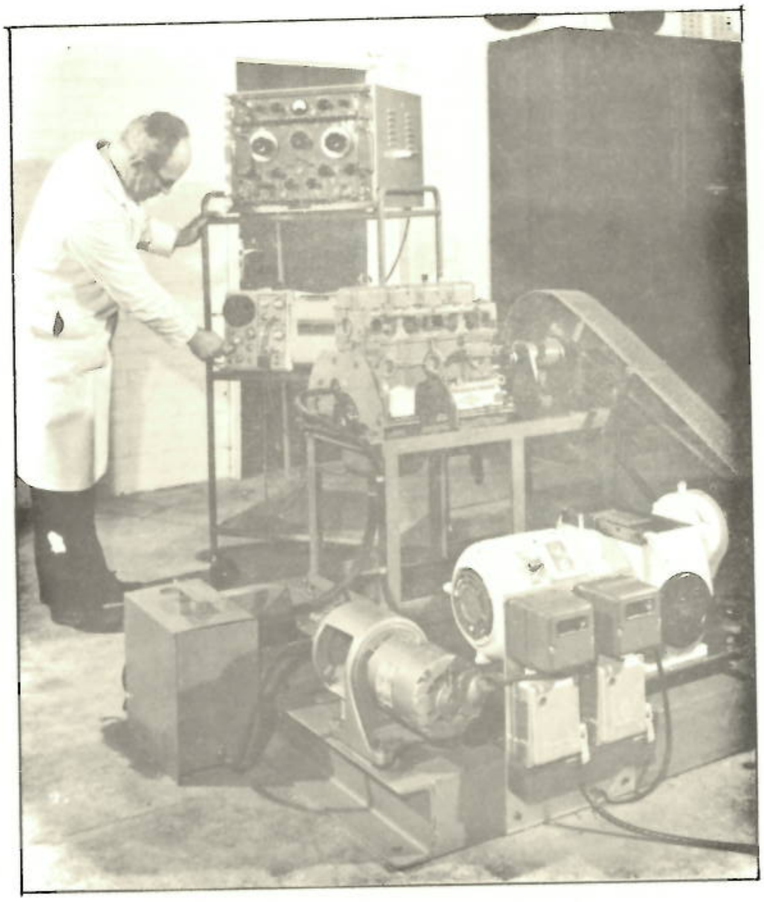
By the researches of students working under the supervision of a member of the A.S.A.E. staff, progress has been made with the analysis of the flexural vibrations of a four throw crankshaft with two planes of vibration. It is the intention to widen the analysis to include crankshafts with more than two planes of vibration, to take account of crankcase resonances and flexibility, to check the validity of the analytical methods by testing a number of crankshafts, and to accelerate the progress of the work so that useful information is available to the engine manufacturers as soon as possible.

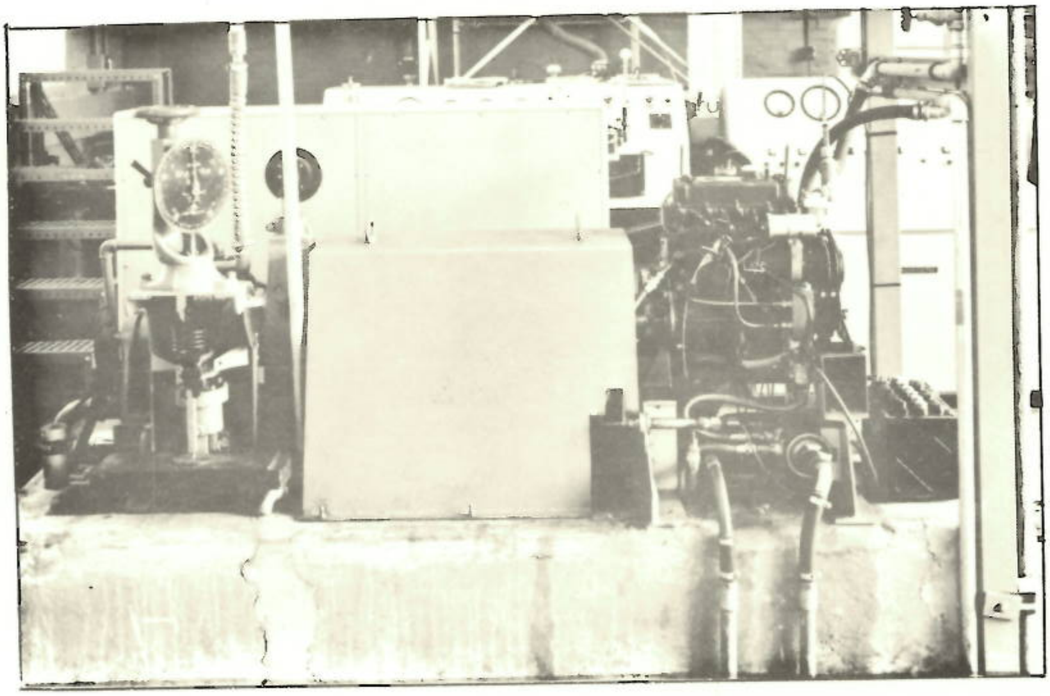
It is particularly necessary to apply the fundamental methods developed to the analysis of a wide range of crankshaft configurations and engine conditions. The repetitive nature of the work and, consequently, the routines to be followed for the collection, reduction and analysis of data, dictate that it is no longer suitable for student research alone and that a professional level of full-time research activity is essential for satisfactory progress. It is the proposal that a Senior Research Fellow and a Research Engineer should be fully employed for three years on a continuation and extension of the research in progress.

The basic apparatus for the testing of four-throw crankshafts either statically or dynamically is already available within the School. To extend the work to other types of crankshaft it will be necessary to design and manufacture additional rigs and to mount the engines on the test bed for the operating tests when required. Financial support is also requested for the provision of additional instrumentation where this does not already exist within the School or where it is not readily available for the purposes of this investigation.

Crankshaft Testing Apparatus

Item		£	
1.	Universal testing machine for crankshaft stiffness	1500	*
2.	Rig for free-free vibration of crankshafts	400	*
3.	Rig for motoring tests of four-throw crankshafts	1000	*
4.	Rig for motoring tests of six-throw crankshafts	1000	
5.	Engine installation and test bed - four cylinder engine	2500	*
6.	Engine modification and installation - six cylinder engine	500	
7.	Consumable items	250	
		7150	
	Less items* available in school	5400	
		£1750	





RIG FOR MOTORING CRANKSHAFTS

ENGINE AND BRAKE INSTALLATION FOR CRANKSHAFT TESTS

Instrumentation for Testing Apparatus

Item		£	
8.	Electronic counter for shaft speed	100	
9.	Photo electric pick up and power amplifier	50	
10.	Decade oscillator	300	
11.	Phasemeter	350	
12.	Force transducer and charge amplifier	300	
13.	Cylinder pressure transducer	90	*
14.	Electromagnetic vibrator and power amplifier	550	*
15.	Displacement transducers and amplifiers - 6 off	300	*
16.	Capacitance type displacement transducers and amplifiers - 2 off	440	
17.	Microphone and sound meter	250	*
18.	Automatic wave analyser	1000	*
19.	Dual beam oscilloscope	250	*
20.	Strain gauges and slip rings	150	
21.	F.M. tape deck	5000	*
22.	Consumable items	200	
		9330	
	Less items * available in school	7440	
		£1890	

Staff

	Salary	N.I. etc.	£
1 Senior Research Fellow for three years	£4950	£675	5625
1 Technical Officer for three years	£3375	£345	3720
			£9345

Totals

Crankshaft Testing Apparatus	£1750
Instrumentation Testing Apparatus	1890
Staff	9345
	£12985

References

1. An investigation of crankshaft behaviour
   C. F. Stormont — A.S.A.E. Thesis 1962-3

2. Crankshaft main bearing loads
   R. Ali — A.S.A.E. Thesis 1963-4

3. C rankshaft main bearing loads
   B.N. Chaudhari — A.S.A.E. Thesis 1964-5

4. Precessional vibrations of heavy shafts
   D.A. Griffen — A.S.A.E. Thesis 1964-5

5. Bending vibrations of a crankshaft
   M.R. Saville — A.S.A.E. Thesis 1965-6

6. Engine main bearing loads
   D. Hodgetts — Automotive Design Engineering May 1966