Prediction and Simulation of In-Service Conditions

PREDICTION AND SIMULATION OF IN-SERVICE CONDITIONS

IMechE CONFERENCE PUBLICATIONS 1985–5

Sponsored by
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The Institution of Mechanical Engineers
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Fédération Internationale des Sociétés d'Ingenieurs
des Techniques de l'Automobile

22–23 May 1985
1 Birdcage Walk
London SW1

Published for
The Institution of Mechanical Engineers
by Mechanical Engineering Publications Limited
LONDON

First published 1985

ISBN 0 85298 561 4

Printed by Waveney Print Services Ltd, Beccles, Suffolk

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Selection criteria for simulation test systems

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SYNOPSIS

This paper discusses aspects of the design, specification and acceptance testing of modern computer controlled simulation test systems for components and sub-assemblies.

The selection of a suitable test technique, and the contents of a detailed system specification are presented as central factors in the speedy and efficient realisation of a test requirement.

The usefulness of planned formal design reviews and the role of careful acceptance testing before final commissioning are presented.

Each point is explained by reference to activities carried out during the procurement of a recently installed 6 channel simulator.

1. INTRODUCTION

Modern testing techniques offer the possibility of almost perfect reproduction of the real working conditions of automotive components and sub-assemblies (1, 2, 3). However, the more novel and complex the test system, the more unlikely it is to work properly first time. Multi-channel systems are very much more than the sum of their parts and the delays caused by the necessity to sort a new system before it can contribute positively to a product development frequently run into months and even into years.

During preparations for purchase and installation of the six parameter road simulator - DYANA (4) shown in Figs. 1 and 2 it became apparent that a) some existing systems are not being used to their full accuracy or simulation potential (i.e. they were overspecified) b) some had taken far longer to design, manufacture, install and pass acceptance testing than planned (i.e. project management was poor) c) it was likely that some users did not appear to know the accuracy of their test, short or long term and d) in some isolated cases "unacceptable" test systems have been accepted (i.e. acceptance testing insufficiently defined and poorly carried out).

Considering that the full cost of a test installation can be in excess of one million pounds sterling the state of affairs described above must be considered unacceptable.

Comparatively little guidance has been available to the test system purchasers to avoid these initial pitfalls (5), although there is some guidance in how to formulate a test programme using the system (6) and what test method to adopt (7). The remainder of this paper outlines steps that have proved successful in overcoming these problems - if taken with large measures of forward thinking and discipline.

2. SYSTEM CONCEPT

Often a test system layout is fixed far too early in the procurement cycle, due to past history, compatibility with existing methods, or perhaps preconceived ideas of the way to do the job.

For the ideal system it is necessary to start out with a blank sheet of paper. We have a component to test; let us analyze our requirements by listing some factors we should consider before determining even system concept.

(1) What does the proposed test component do?
(2) What loads and conditions are applied to it in all its possible operation conditions?
(3) Which of these are critical, which important and which can be neglected in a test?
(4) What are the load and frequency ranges?
(5) What are the interactions of the loads - are they important?
(6) Is the dynamic content of the loading critical to an understanding of the component performance?
(7) What sort of test scheme is required e.g. development testing of a high risk product or quality acceptance testing of an established product?
(8) Can the test be simplified or must

it be an accurate simulation of service?

(9) Is a short term functional or strength test required or is a longer term failure mode/endurance test required?

(10) If a simulation test, is there reliable access to raw load history data for the component, in representative conditions?

(11) Is this sufficiently accurate to justify simulation of it by advanced computer techniques?

(12) Is technical expertise readily available, long term, in the test laboratory?

- for setting up the test
- for running the test
- for maintenance of the whole system
- for fault finding
- for developing software

(13) Is the component safety critical or requiring special tests?

As an example, consider the SKF Hub Unit 4 (Fig. 3) for which the DYANA system was developed. The test component is an integrated hub bearing unit and constant velocity (CV) joint for driven front wheels.

Answering the above questions for the Hub Unit 4:

(1) The component performs the functions of wheel bearing, structural hub and CV joint in normal automotive applications.

(2) The principal loads are vertical wheel load, lateral (cornering) wheel load, horizontal (brake and drive) load, drive shaft torque, drive shaft angle (made up from a steering angle, a vertical suspension motion and a plan angle offset), and rotational speed. The unit is further subjected to environmental conditions of heat and cold and periods of wet condition.

(3) The vertical and lateral wheel loads, the drive shaft compound angle and the rotation were all considered critical. The horizontal wheel loading would be neglected.

(4) The load ranges were selected at up to 3 times maximum wheel load for the vertical and lateral forces with significant frequency content up to 20 Hz. The torque range was up to 2.5 times the maximum transmission torque output with frequency content reproduced up to 20 Hz again. The steering angle range was potentially up to 50^{o} with a realistic frequency range up to 20Hz for the vertical suspension component of the angle (the steering motion has a maximum frequency less than 1 Hz). Rotational speed was taken as up to 33.4 Hz forwards and reverse with an acceleration requirement of 5.6 Hz/s.

(5) From analysis of road recordings it was determined that maximum stress conditions on the component probably occur due to the combinations of several moderate loads, rather than individual maxima.

(6) Dynamic content is critical as a reproduction of the instantaneous loads, correct in both magnitude and phase, was required.

(7) The first requirement was for a development test on a completely new product.

(8) It was deduced that in the development stages the test should not be simplified. A full simulation test was required.

(9) Long term testing to determine failure mode and service endurance was required in order to judge the fitness of the product for full service life.

(10) Steps were taken to assure that there was an inhouse ability to make road recordings. (This in itself required considerable investment.)

(11) Technical expertise shortcomings in support staff were highlighted at an early stage, giving ample time to train existing staff and recruit new.

(12) The test component is safety critical. This underlined the necessity of doing a most professional test and development exercise with the best possible experimental techniques.

From these answers (particularly answer 6) it is apparent that a six channel load history simulator was required. A good frequency response with high accuracy was necessary. Long term stability of the test was required and, in order to assess functional behaviour, extensive test condition monitoring was proposed. The computer facilities (hardware and software) required for preparation of rig drive signals from road recordings also formed an integral part of the system concept.

In this example a full blown simulator was selected, but in other instances this exercise may clearly show that a simpler machine is perfectly adequate.

3. SPECIFICATION

The system specification is the central factor in a test system purchase. The more complex the system the more important the specification. It provides the performance standard requirement for every aspect of the machine from the design stage to acceptance testing. In principle, the same specification would be used for an in-house manufactured rig as for a Turn-Key system from one of the specialist manufacturers. It is in the interests of both the supplier and the supplied to be absolutely clear on the meaning of every phrase of the specification from the earliest contact. A comprehensive verbal presentation of a specification is most essential. Even those speaking the same language can have misunderstandings - if any material must be translated to another language, chances of mistakes are increased significantly. Be aware of this and always double check the comprehension of your requirements. Time spent at this stage will be amply repaid later.

The specification will cover the many disciplines involved in a modern system - mechanical, hydraulic, electrical, electronics, facility, computer hardware and software. It is important that each area be properly researched. Experts from each sub-segment must be consulted to establish the state of the art capability consistent with the system concept established previously. e.g. in terms of accuracy, stability, response, software capability.

It is strongly recommended that specialist external consultants are used to provide input for a major contract. Techniques, particularly those computer based, are developing so fast that only the large test laboratories, placing frequent orders for test equipment, can adequately keep up to date. Money spent on a specification should be considered as part of the system cost and can repay itself handsomely by savings later.

The specification can be considered at several levels. An overview should present the system concept, (the testing methods envisaged, sketch surrounding facilities and the installation situation in the test laboratory). The scope of the system will be defined and a clear definition of responsibilities. A segment by segment presentation should detail general requirements (e.g. mechanical loading ranges, hydraulic safety codes). A detailed section will precisely define the required properties (e.g. transducer accuracy, computer memory capacity).

The details of any specification will obviously reflect the particular requirements of the test system to be installed but on the DYANA system the following chapters were included and will provide an example of how the details were defined:

(1) SYSTEM OVERVIEW
(2) TEST MACHINE
(3) ELECTRONIC EQUIPMENT
(4) HYDRAULIC EQUIPMENT
(5) COMPUTER HARDWARE AND SOFTWARE
(6) ADDITIONAL ITEMS
(7) DESIGN REVIEWS
(8) ACCEPTANCE TESTS.

Looking at this in more detail.

1) SYSTEM OVERVIEW

1.1 System concept (as described above)

This system was purchased from an external manufacturer.

1.2 Derivation of drive signals

Statement of the requirement for the time and motion histories to be simulated from actual response data.
Definition of each of the 6 response parameters which must be simulated. (Use of figures clearly showing the co-ordinate system and terminology is recommended.)
Statement that the system must have the software capability to digitise, edit and combine time histories of these 6 parameters.
A requirement for the minimum length of drive block is included here.

1.3 Initiating a test

Descriptions of the requirement to create a drive signal which will result in the desired response history being reproduced. The necessity for the ability to run an iterative process is stressed.
In practice this requirement can only be satisfied by the advanced drive signal computer control systems such as Remote Parameter Control (RPC) (8, 9), or Iterative Transfer Function Compensation (ITFC) (10).

1.4 Test specimen condition monitoring and data analysis during a test

A description of the test specimen performance parameters to be monitored and the reduction and analysis to be carried out on the data, e.g.,

a) Continuous measurements of temperatures (on rotating and non-rotating parts, positions specified). The maximum value and time spent above a value required to be charted.
b) Continuous monitoring of lubricant condition in the test unit bearing rows. (An SKF developed transducer was supplied for this parameter.) The minimum value per response block being required for long term trend analysis.
c) Strain measurement at two rotating positions, such that it is possible to analyse the strain/time histories after a test to provide fatigue statistics.
d) Wear in the C.V. joint to be measured as angular play for backlash in the unit. One value is required per response block for long term trends. If the value exceeds a specified value, the test must stop automatically.
An outline of the requirements for computer software to enable short term data and long term trends to be stored and presented is included.

1.5 Other desirable features

This section indicated the other test systems that were installed in the test laboratory and requested the possibility to adapt the new facility to handle other test rigs.

2) TEST MACHINE

2.1 General

To avoid unnecessary design work the general principle for the test rig of a four-square design was stated. During the system concept stage it had been established that this was the most realistic approach. If the design choice is open it should be described accordingly.

2.2 Function

The six dynamic loads and motions required on the rig were defined. At this point the C.V. joint angle was defined in terms of the jounce (suspension) motion and the steering angle.
It was required to create identical load and motion situations simultaneously on each of the four test specimens. This was an important point for the simulation and the specification included a requirement for the supplier to supply loading diagrams for each test position and text to justify his choice. Two driving situations were defined for the loading diagrams: the situation of the right-hand unit on a car accelerating out of a right-hand corner and the situation of the left-hand unit on a car accelerating out of a left-hand corner.

2.3 Operation

The system was required to be operable independently of the computer. Dynamic loads and displacements must be applicable to the specimens using suitable analogue signal generation equipment.

2.4 Load and displacement actuation

The individual load ranges, frequency response curves and rate of change of signal were defined for each channel (table 1). The values were based upon earlier road data analysis uprated to the largest vehicle that may be tested. It is important to be realistic with maximum load and torque requirements - too large actuation will not only result in a more expensive machine, but will give inferior frequency response and poorer absolute accuracy at the lower load values which they will normally be producing.

2.5 Mechanical arrangement

The range of test specimens to be accepted were specified. This included dimensions for hub and wheel bolting arrangements, drive shafts lengths, tyre radii and wheel load lines.

2.6 Mechanical and electrical safety

Observance of the relevant local safety requirements were specified and a general requirement for safety guards noted.

2.7 Machine life

A design life of 30 000 testing hours was required. Design calculations were required for critical areas. A minimum of 500 hours continuous running between any maintenance requirements was specified.

3) ELECTRONIC EQUIPMENT

The supply of all electronic equipment required for operation of the test system was required. All quotations were requested to include a specification of the control equipment proposed, giving details of

- noise
- linearity
- drift
- type of instrument
- monitoring points
- analogue control panels

Maximum requirements for the performance aspects - noise, linearity and drift should be specified. In long term testing drift is of particular importance and should be quoted in terms of zero and signal drift.

The test engineer requires absolute transducer accuracy maintained over the whole test period with an infrequent need for recalibration. The accuracy of the test simulation he is performing is measured by the rig transducers and therefore any inherent inaccuracy in them will add to the errors of the load history reproduction.

4) HYDRAULIC EQUIPMENT

The choice of equipment is left open but calculation and specification of the necessary installation are requested.

5) COMPUTER EQUIPMENT AND SOFTWARE

The computer software requirement was given in terms of the input-output processes.

- Data digitisation
- Data analysis
- Response block composition
- Drive file correction
- Durability test
- Monitoring of durability test

In some modes of operation several processes are required in parallel. These combinations were specified.

A series of preferred computer system organisations based on the PDP11 processor were specified in the DYANA case but this is not necessary if there is no preference.

The method of analogue input and output to and from the computer system was specified in some detail. Experience has shown that the performance of the anti-aliasing filters, analogue to digital converters and digital to analogue converters are crucial to minimising phase errors between channels.

6) ADDITIONAL ITEMS

6.1 Documentation

Copies of the documentation appropriate to the running and maintenance of the system were specified. The supply of adequate documentation is one of the most important aspects of the long term success of a complex simulation test system. This must be emphasised at every available opportunity, so that sufficient resources are allocated to its preparation. The user manuals in particular must be completed accurately while the rig details are still fresh in everyone's mind.

Equipment suppliers often write manuals to suit their own maintenance engineers. This will not be the layout that a user requires. In particular the interactions of mechanical/electronic/computer systems must be described.

Avoid standard descriptions, with modification sheets to describe the differences to be found in your one-off system.

The cookbook style of system manual is often derided on the basis that it encourages inexperienced or untrained operators to drive the system. This is rubbish. A cookbook-like listing of operations, in the order that they must be carried out to set up and operate a test, should be used by even the most experienced operators to ensure a safe test.

The full documentation requirement will consist of:

1) Operation manuals.
2) Maintenance manuals.
3) Software run guide manuals.
4) Diagnostic software and hardware fault location manuals.
5) Programmers' manuals.
6) Drawings of the mechanical system parts.
7) Spare parts listing.

6.2 Spares and Tools

A priced list of recommended spare parts for the continued operation of the system was required. An adequate spares inventory to ensure minimum down time is expensive - perhaps 10% of the capital cost of the system. It is necessary to adequately budget for spare parts when first considering a system purchase.

6.3 Maintenance

If it is envisaged to take out a maintenance contract then the proposed terms of that contract should be requested.

6.4 Training

Training of sufficient personnel in operation and maintenance of all aspects of the test system is essential. It is a false economy to train, say, two senior engineers in the hope that they will successfully pass on all the details to junior staff.
Economics obviously must play a part, but it is not unreasonable to request full training for a team consisting of two test engineers, two rig technicians, one computer software engineer and one electronics engineer.

The training programme will include both classroom sessions and on rig work. Ideally this should be carried out on the manufacturer's premises during the last stages of the system shakedown. The same team would have responsibility for acceptance testing.

The course must include every aspect of the system - fixturing of specimens, mechanical adjustments, electronic controls, computer routines, preparation of a test run, maintenance and fault diagnosis. Course duration may well be 5 to 7 weeks on a complex system. This is obviously not a job to be taken lightly, hence the need to include it in the specification so that the course can be properly costed and planned.

6.5 Installation

The facilities required for the final installation of the system must be known - control area, rig safety enclosures, ventilation, perhaps a seismic base, perhaps an uninterruptable power supply to computers. Cooling water requirements and power consumption loading for hydraulic power supply can be particularly problematic.

6.6 Timescale

A timescale is needed for planning purposes and will form part of the contractual agreement for the purchase. Probably the less said about meeting time targets the better. It is often a major source of irritation, particularly during the closing stages of a project. Be realistic and then add a safety margin to your time estimates.

7) DESIGN REVIEWS

The requirement for design reviews should be part of the specification, together with the rough timings and proposed contents.
Design reviews are described in some detail in section 4.

8) ACCEPTANCE TESTS

The acceptance tests to be carried out before a system is deemed acceptable must be specified in advance. Changing requirements at the last moment is justifiable cause for complaint by the manufacturer.

4 DESIGN REVIEWS

The use of formal, documented, design reviews (11), held between senior expert staff of the test system purchasers and the test system manufacturers are the only way to obtain the right system for the job - first time round.

From the DYANA system experience it seems that four design reviews are not excessive in a project taking 18 months from order to acceptance. The aim of the meetings is to obtain agreement for proposed design and procedures before they are implemented, thus eliminating the need to redesign unacceptable solutions at the final acceptance test stage. The improved efficiency resulting from the design review procedure is of benefit to both sides of the agreement.

It may be appropriate to consider mechanical designs, electronic designs, computer hardware/ software and facilities as four separate reviews; or regular reviews mixing all aspects as they reach critical points may be more appropriate. Concentration on one area for each review will usually mean less staff attending the meeting, which is usually more efficient (and cheaper), so is to be preferred, provided one person (the project leader) on each side can carry the overview.

Every decision - approval, rejection, request for change, need for more information, whatever - must be minuted with the responsible person and time limit for response noted. Discipline in this area is essential.

Ideally, the reviews should overlook every design decision that is made on a system. In practice this can be comprised as packages of existing equipment and software are often used in a 'new' system. Reviews will tend to concentrate on the novel aspects requiring extensive innovation. The contributing staff on the purchaser's side must be of at least equal technical ability to those on the designing side, otherwise reviews will become one-sided presentations. Useful, but not good enough. It may, therefore, be advisable to bring in consultants in areas where the purchaser is technically weak.

5. ACCEPTANCE TESTS

The objective of an acceptance test programme is to prove that an installed test system meets all the requirements of its specification and includes all items of its quotation from the supplier. Further, it will enable absolute levels of accuracy and performance to be ascertained for each sub-system and the whole system whilst operating in analogue and digital modes.

Often a system is assembled at the manufacturers for development and proving prior to strip-down and re-assembly in its final laboratory position. It is then advisable to carry out the full test programme at the manufacturers (check-out tests) and only repeat critical checks in the final position (acceptance tests).

Careful planning of the check-out test sequence will result in isolation of faults or non-compliance at the point at which they occur rather than have them show up as a major process error, which may be diagnosed only with difficulty.

The flow charts for checkout of the DYANA system (Figs. 4 & 5) are examples of a procedure which has been successful. All checkout and acceptance work must be carried out by the purchaser's staff with one authorised person having the responsibility to approve or reject each test. Variations to the specification must be settled quickly to the satisfaction of both parties, rather than be allowed to hold work up. A recent paper illustrates the methods that can be used to handle negotiations (12).

5.1 Referring to Fig.4, the first step is a thorough visual inspection with all power off. The facility should be checked for good workmanship and installation practice. All components, special tooling, critical spare parts, user documentation and drawings must be checked against the quotation. All interconnections must be correctly made - mechanical, hydraulic and electrical. All equipment, including computer hardware, should be checked and measured to ensure that the electrical grounding is satisfactory with no ground loops. Electronic circuit boards should be further checked at this stage to ensure that only new components have been used, that there are no temporary circuit arrangements, that the printed circuit boards are clean, that wiring practices are sound and that components are working within their prescribed operating range.

5.2 When the visual inspection is completed, the system may be switched on and the independent system checks carried out.

5.2.1 Computer checks (carried out independently of the test rig).
The standard computer system diagnostic checks should be run to prove good function. All add-on equipment (array processors A to D and D to A converters, anti-aliasing filters) should be exercised using diagnostic software. The accuracy of A to D, D to A and the roll-off of the anti-aliasing filters should be checked.
All programmes must be shown to be installed and functioning correctly. Special tests may be required to ensure that the programs are tested in all their modes of operation.

5.2.2 Mechanical system

It must be demonstrated that the complete range of test specimens and adjustments can be accommodated as specified.

5.2.3 Hydraulic system

All parts should be checked against specification and quotation. The system, as installed, should be leakfree with clean oil (as demonstrated by oil analysis after a period of running.)

5.2.4 Electronic system

The transducers, signal conditioning and wiring must be calibrated to normal standards using standard transducers. The calibration documentation must be provided with the system. Transducers should be calibrated in each of their ranges, and the influence of temperature (during worst case rig operation) on both zero (i.e. no load) and gain should be measured.

5.3 Steady state instrumentation checks

These are carried out channel by channel using the test facility installed instrumentation. Their purpose is to quantify measurement accuracy and signal-to-noise ratio. The reference instrumentation used to make the reference measurements should be at least an order of magnitude more accurate than rig transducers.

5.4 Dynamic performance checks

A channel-by-channel dynamic performance test without computer control. Generally the aim of each test is to produce plots of feed-back signal to command signal amplitude ratio versus frequency, and phase shift between feedback signal and command signal versus frequency. The other channels should be at their zero or a fixed constant position.

It is required to demonstrate system performance at the maximum specified values of each control parameter and to show that any resonances do not affect the performance within the specified operating ranges.

5.5 Simulation software check

Proper operation of all test channels under computer control should be demonstrated by completing one drive signal iteration loop to produce a sensible modified drive signal. The iterations will normally be continued to arrive at the optimum drive signal.

5.6 Simulation accuracy check

The accuracy with which the test rig will reproduce road recorded load data at the test specimen is the central point to a simulation system. A suggested method of defining simulation accuracy is to calculate the instantaneous error between signal response signal and the desired response signal. Calculate the root mean square (RMS) of this instantaneous error over each 10 second section of the signal. This error must not exceed the allowed percentage of the RMS of the desired response in any section for a successful simulation. An allowed error of 4% of the desired response was used in the DYANA system and was easily achieved within 5 iterations.

5.7 Endurance test software check

Typically an endurance test will consist of a number of cycles made up of a combination of drive files obtained from road test data. Proper operation of the cycle, under computer control alone, must be demonstrated.

5.8 Test monitoring software check

During an endurance test proper operation of any test monitoring and data analysis software must be demonstrated. Alarm and limit switching must be shown to operate satisfactorily.

5.9 System endurance test run

If the test system is intended for unattended long term endurance testing, this feature must be demonstrated by such running over a realistic test time. A continuous run of at least 50 hours is recommended.

5.10 Check-out approval

When the system has passed all the tests described above, it can be approved for stripping, packing and transit to its permanent site for final commissioning and acceptance testing.

6) COMMISSIONING

Installation of a system in its final position - with seismic base, proper cooling, controlled atmosphere control room - and all the development problems finally solved - should result in a better quality test. This should be checked by repeating the most critical performance checks and certainly running through the drive signal iteration procedure to obtain a new drive signal and new error values.

If satisfactory, the system can be accepted and the real work begin.

7) CONCLUSIONS

Every test system will have its own particular design features and problems. Reference to the DYANA system has naturally highlighted the important features of that rig, which may not be applicable to other systems. However, the principles described are universal and if carefully applied will result in a better system and a better trained operating staff.

8) ACKNOWLEDGEMENT

The author wishes to thank the management of SKF UK and SKF ERC for permission to publish and the members of the SKF-ERC DYANA project team for their encouragement and help in following the main points of this paper.

REFERENCES

(1) MANDUZZI, J. and REID, K.E. Fords new programmable front wheel drive half shaft test system. Closed Loop (MTS publication), June 1980, pp 3-18.

(2) TELSCHOW, J. Dr. Testing drive axles and shafts with flexible couplings for front wheel drive vehicles. Closed Loop (MTS publication), 1974.

(3) PETERSEN, J. and WEISSBERGER, G. The conception, description and application of a new vehicle endurance test system at Audi, NSU. Paper presented at SAE Congress, Michigan USA, Feb. 1982.

(4) HERRATY, A. G., de BROUWER, R. and NOLAN S.A. DYANA - A dynamic simulation test system for automotive driven hub arrangements. Paper presented at Driveline 84 Conference, I Mech E. London March 1984.

(5) DONALDSON, K.H. Jr. and DABELL, B. Decision path guidelines for applying digital testing techniques in fatigue service simulation. Paper presented at SAE Congress, 1982.

(6) LUND, R.A. and DONALDSON, K. H. Jr. Approaches to vehicle dynamics and durability testing. Paper presented at SAE Congress, Michigan USA, Feb. 1982.

(7) ZOMOTOR, A., SCHWARZ, K. and WEILER, W. Simulation methods for evaluating passenger car ride comfort and the fatigue strength of Vehicle Components. Paper presented at SAE Congress, Michigan USA, Feb. 1982.

(8) CRYER, D.W., NAWROCKI, P.E. and LUND, R.A. A Road simulation system for heavy vehicles. Paper, SAE 7603614.

(9) PETERSEN, J. Dr. and WEISSBURGER, G. The Audi road simulator. Closed Loop (MTS publication) Summer 1984.

(10) CRAIG, J.B. ITFC - How it works and where to use it. Publication, Schenck, 1979.

(11) JURAN, J.M. Dr. Quality Control Handbook, 3rd Edition. pgs 8.8. to 8.10. published McGraw - Hill.

(12) MEAKINS, E. J. and McCABE, T.I. Variations. Proc. Instn. Mech. Engs. Vol. 198B No.14.

Table 1 DYANA - Performance requirements (Range of 6 simulated parameters)

	Maximum values	Qualifying conditions	Frequency Range
Lateral force	± 25 kN		0 - 20 Hz
Vertical force	± 25 kN		0 - 20 Hz
Torque	± 2500 Nm	± 100 deg.	0 - 20 Hz
Speed	± 33,4 Hz	5,6 Hz/s	0 - 1 Hz
Steering angle	± 50 deg.	60 deg/s	0 - 1 Hz
Jounce	± 125 mm	1,57 m/s	0 - 20 Hz

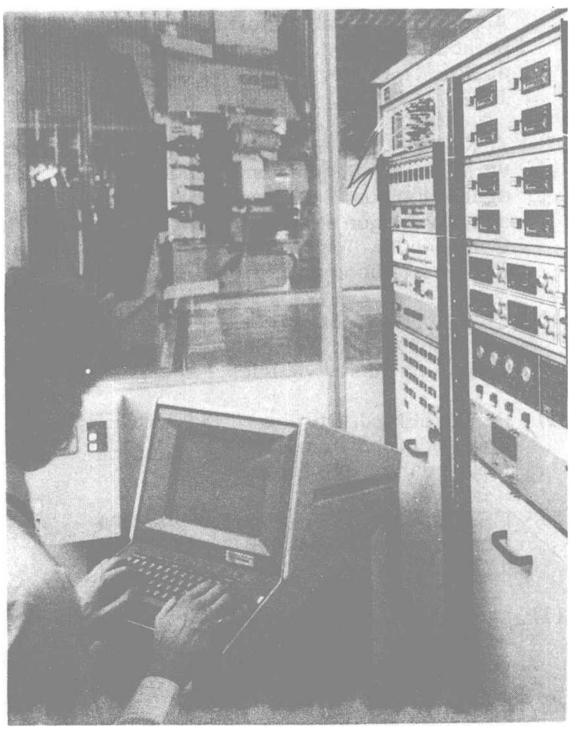

Fig 1 DYANA test system – control room

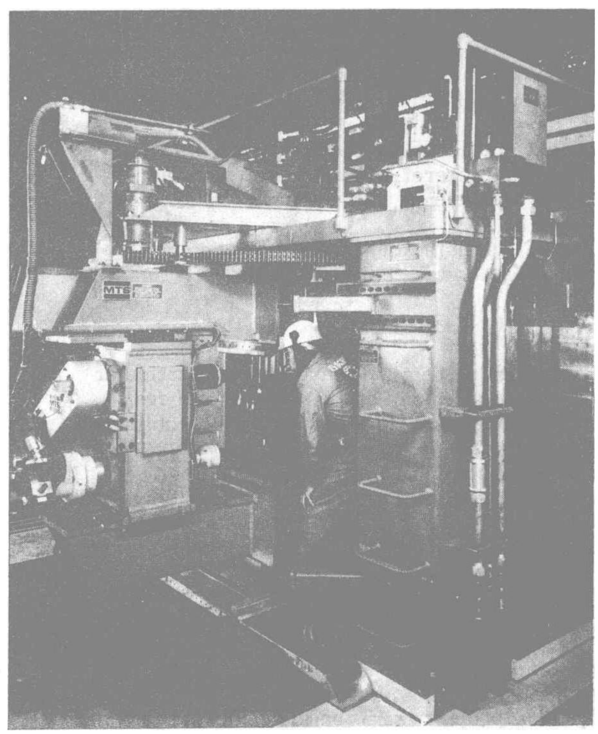

Fig 2 DYANA test system – mechanical assembly

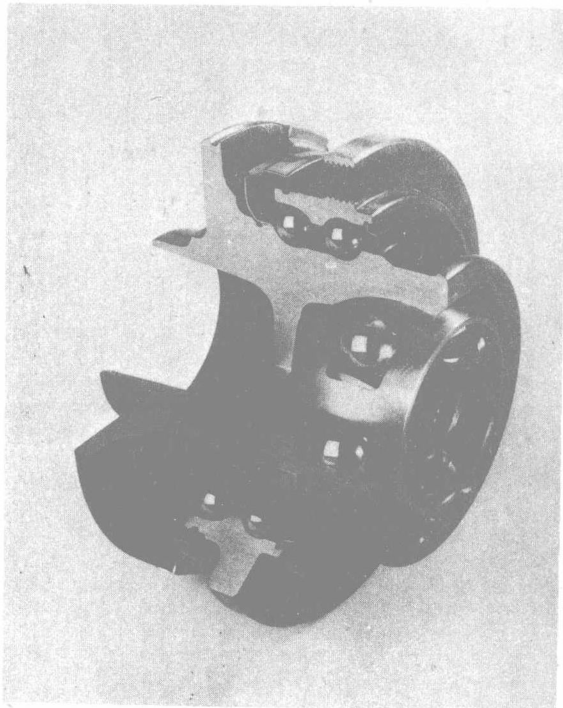

Fig 3 SKF Hub Unit 4 – bearing, hub and CV joint

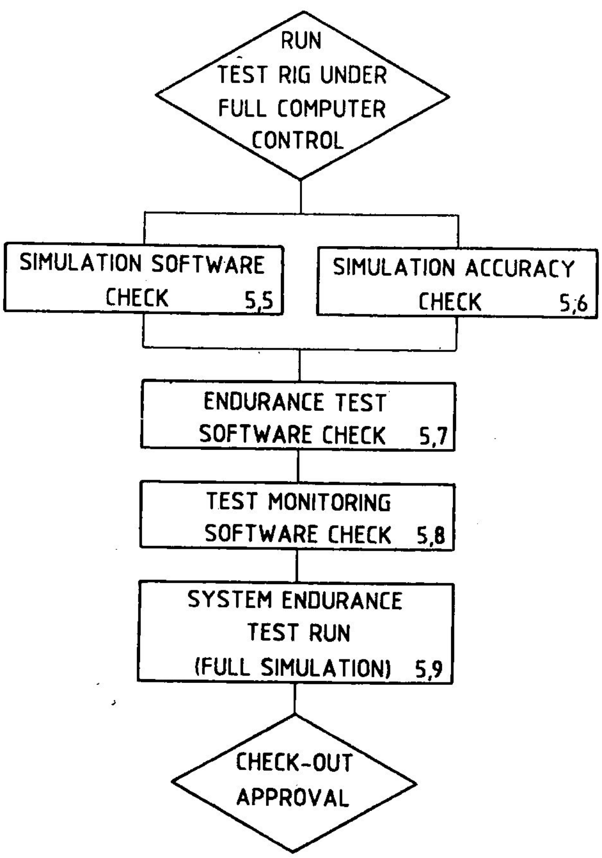

Fig 5 Check-out flow chart – computer control

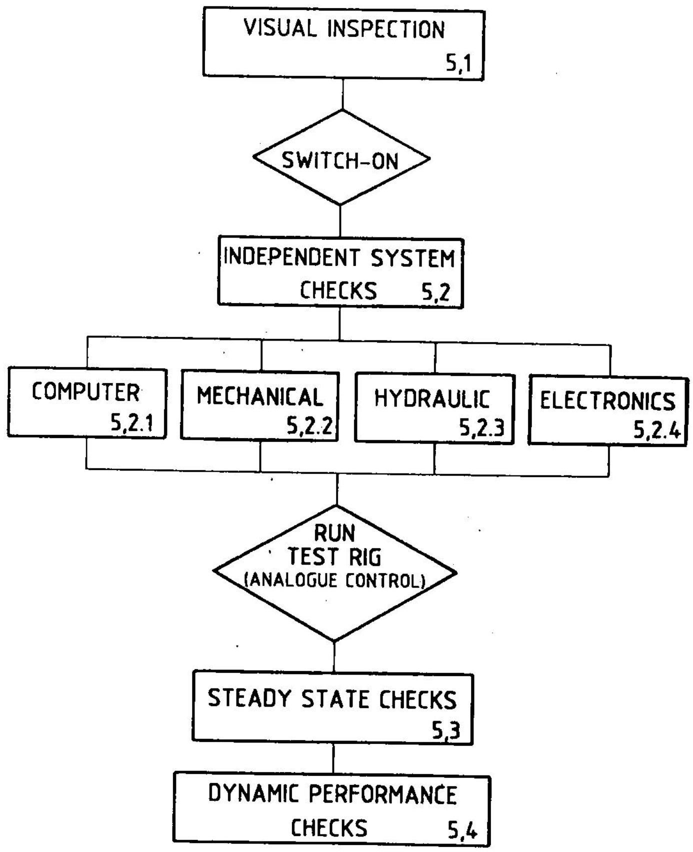

Fig 4 Check-out flow chart – analogue control

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Techniques for endurance testing of automotive driveshaft components

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ABSTRACT

This Paper discusses the evolution of rig testing techniques as applied to driveshaft components. How, since the concept of the modern front wheel drive vehicle, it has been necessary to develop procedures and equipment to ensure the product meets the stringent demands of the application. The Paper reviews the relationship between rig and field-acquired data and considers the adequacy of current test methods.

INTRODUCTION

With the concept of the mass-produced front wheel drive vehicle in the 1950's there dawned a new motoring era. The demands, however, for a service free constant velocity (C.V.) driveshaft required the development of special seals, lubricants and metal components of a very high order of reliability due largely to the fact that the driveshafts are a crucial part of both the steering and transmission system.

The reliability of the product must therefore be known with a high degree of certainty. Component failures, if and when they eventually occur, must be preceded with ample warning, similar to that associated with other transmission components such as gearboxes, differentials, wheel bearings etc.

To accumulate such intimate knowledge of the products long term performance inevitably demands exhaustive testing covering every aspect of loading and environment. Unlike many other transmission components the drive-shafts are exposed to the very worst of conditions, being bombarded with salt water, ice and snow in winter, and extremes of heat and dust in summer. They must be designed to withstand the extremes of loading and suspension movement resulting from abusive operation often experienced during rallying or police work but not be over-engineered to make them bulky and commercially uncompetitive. Data gathering has played a major role in enabling the correct product to be chosen that will totally satisfy the customers' stringent specification. It has enabled test programmes to be evolved which simulate every combination of road mix, proving ground, and environment, either in compressed block form or real-time.

Some engineers believe it may be possible, with the rapid advance in computer techniques, to obviate the necessity for physical testing and enter full scale production directly from a design. Such a system would require a very high degree of confidence and it is significant that even in the most advanced engineering, such as exists in the aircraft industry, comprehensive test programmes are still necessary. The motor component industry possibly following slightly behind in such high technology will therefore have to invest in and rely on the test department for the foreseeable future.

REQUIREMENTS OF PHYSICAL TESTING

The major requirements covering the testing of driveshaft components can roughly be classified as follows:-

(i) Ultimate and yield strength

(ii) Fatigue resistance

(iii) Dynamic durability of load bearing surfaces

(iv) Sealing and resistance to the environment

Satisfactory compliance with these four major requisites ensures that the product will not cause loss of drive and will not deteriorate prematurely to give a vehicle model a poor reputation which can seriously affect future sales.

ULTIMATE AND YIELD STRENGTH

With driveshafts incorporating universal joints, the ultimate strength can be determined and identified in two forms:-

(A) The static strength i.e. without revolving.

(B) The quasi-static strength i.e. when revolving and articulating dynamically.

A. Static Strength - Johnsonian Apparent Elastic Limit (J.A.E.L.)

This is determined by the simple technique of applying an increasing torsional load until failure. The torsional deflection of the various portions of the driveshaft are determined to reveal relative stiffness and yield based on the Johnsonian principle of a 50% increase in the slope of the stress-strain graph (Ref. 1). The universal joints are set at zero angle and held in adaptors which simulate the wheel and differential mountings of the vehicle. The static strength value obtained is then related to the vehicle application data found either from calculation or road load measurement if available. A suitable safety factor covering shock loading and duty cycle is taken into consideration.

B. Quasi-Static Strength

This is more truly an indication of the driveshaft's ultimate dynamic strength as required by the vehicle in operation. It takes into account the resultant forces of torsional load which are applied to the joint's internal components when required to transmit torque through an angle. In a vehicle, maximum torque can be applied just as easily on full lock as in the straight ahead condition. Possibly the worst situation arises when a vehicle fitted with an automatic transmission is parked against a high kerb with the wheels at full lock and stall torque is required at very low driveshaft speed to extricate the vehicle. Similar situations can be expected during rallying, with high torsional shock loads under slip-stick conditions when cornering.

To determine the quasi-static strength of a constant velocity joint a special test rig is required with a high gear reduction drive to produce a high torsional load at low speed - typically 3,000Nm at 30 - 50 rev/min. Load is transmitted by the joint at various angles via a connecting shaft and absorbed by a brake. The test procedure entails gradually increasing the applied load at a constant rate until failure occurs. Tests are conducted on individual sets of joints at different angles. This produces different modes of failure because the dynamic forces applied to individual components vary with the joint angle. As a general rule the joint is weakest at maximum angle and failure is likely to be in the cage which becomes highly stressed due to cage steering forces. The release of energy when a cage failure occurs is spectacular and often results in the whole joint shattering, but without failure of connecting shafts or joint shanks.

Testing has shown that the cage is the most critical component in a ball type C.V. joint and accordingly it is under constant development, and subjected to maximum scrutiny during manufacture. Fig. 1 indicates typical failure modes experienced during quasi-static testing.

FATIGUE RESISTANCE

Fatigue mechanisms in driveshafts fall into two basic categories:-

A. Torsional fatigue which is imposed on the whole assembly including end connections and interconnecting shaft between the joints.

B. Fatigue induced by complex stresses in the C.V. joint components whilst revolving and articulating under load.

Failures from fatigue of either type could render the vehicle immobile and therefore must not be allowed to occur during its service life.

A. Torsional Fatigue

The basic concept of fatigue analysis involves the construction of S/N curves from a representative quantity of components tested at various torque levels below the J.A.E.L. This enables a reasonable prediction to be made of fatigue life at any stress level. When the opportunity arises, comparisons are made with field data fatigue predictions derived from Rainflow counting of stress cycles (Ref. 2 and 3). This enhances the level of confidence when considering economic designs. In practice the S/N curve for a complete driveshaft rarely conforms to the classical shape achieved by constant section test pieces, this is probably due to the different stress levels within the individual components.

When batches of components are tested at a common torque loading the Weibull analysis technique is employed to statistically analyse variations in fatigue life (Ref. 4).

Various types of rig are used for torsional fatigue testing, including fixed stroke crank systems, oscillating mass resonance types and servo hydraulic actuators. The preferred loading is either uni-directional or non-zero mean bi-directional loading, which are easier to relate to field events, but zero mean bi-directional testing is sometimes employed, in order to effect a considerable time saving (Fig. 2). The latter appears satisfactory for comparative testing of similar components but can be damaging to welds or other features with high notch factors, introducing a failure mechanism not experienced in the field. An example of this is a truck propeller shaft application, where spline stub failure which occurred in service could not be reproduced on the rig, as tube weld failures always terminated testing. Resorting to unidirectional testing eventually reproduced the exact service failure mechanism.

Unlike dynamic endurance testing of bearing surfaces the prediction of fatigue life from road data must include a very generous safety factor. This is to accommodate the many