Chapter 2

Research task

Application experience with the recently developed QanTiM time domain based simulation package is limited if compared with its frequency domain counterparts. Considering a development span of less than half a decade, the achievements in the field of time domain based service load simulation is most definitely laudable, yet little has been published on the industrial application thereof. This is simply due to the very recent development of time domain simulation techniques. On the other hand, for more than two decades operational experience using frequency domain simulation techniques have been documented and published by both users and manufactures of these systems. [63][25][19][20]. RPC and ITFC user group meetings, of typically 100 delegates, where application experience is shared amongst other users are not uncommon. It was thus proposed to embark on a research program that would attempt to improve the general application of the QanTiM system and partly alleviate this information backlog. The research was aimed directly at improving the existing QanTiM package and will regularly refer to associated aspects. Details on the functioning and operation of QanTiM are presented in Appendix G.

2.1. Typical simulation problems

The state-space time domain compensation technique proved effective in modelling and subsequently simulating service responses for most structural test rigs [45][50][61]. There are however rigs for which a good dynamic model could not be found, resulting in poor simulation results. Typical examples of simulation problems include:

- Difficulty in recreating high response amplitudes.
- Inaccurate simulation of high frequency responses.
- A large number of iterations is required before accurate simulation results are achieved.
- Failure of iterations to converge to desired response.
- Divergent linear solutions.
- Difficulty in handling structural resonance within the normal operating spectrum,
- and in extreme cases a general inability to model the dynamic behaviour of the system.

Most of these problems are simply due to limited experience in time domain modelling, more specifically, a lack of knowledge on input parameters and operating procedures for QanTiM. Possible causes and solutions to these problems were sought and are presented in the following Sections.

2.2. Origins of poor simulation

The success of system identification for response reconstruction, or more specifically QanTiM, is to a certain extent governed by user definable input parameters. There are unfortunately also parameters that are rig specific and can not easily be modified by the system identification engineer. On the other hand, certain test rig integrity factors such as servo-control accuracy, mechanical backlash in links, incorrect instrumentation settings, etc. are usually easy to trace and rectify, but often confused for modelling problems. Some of the aspects that could adversely affect simulation results are presented in Figure 2.1.

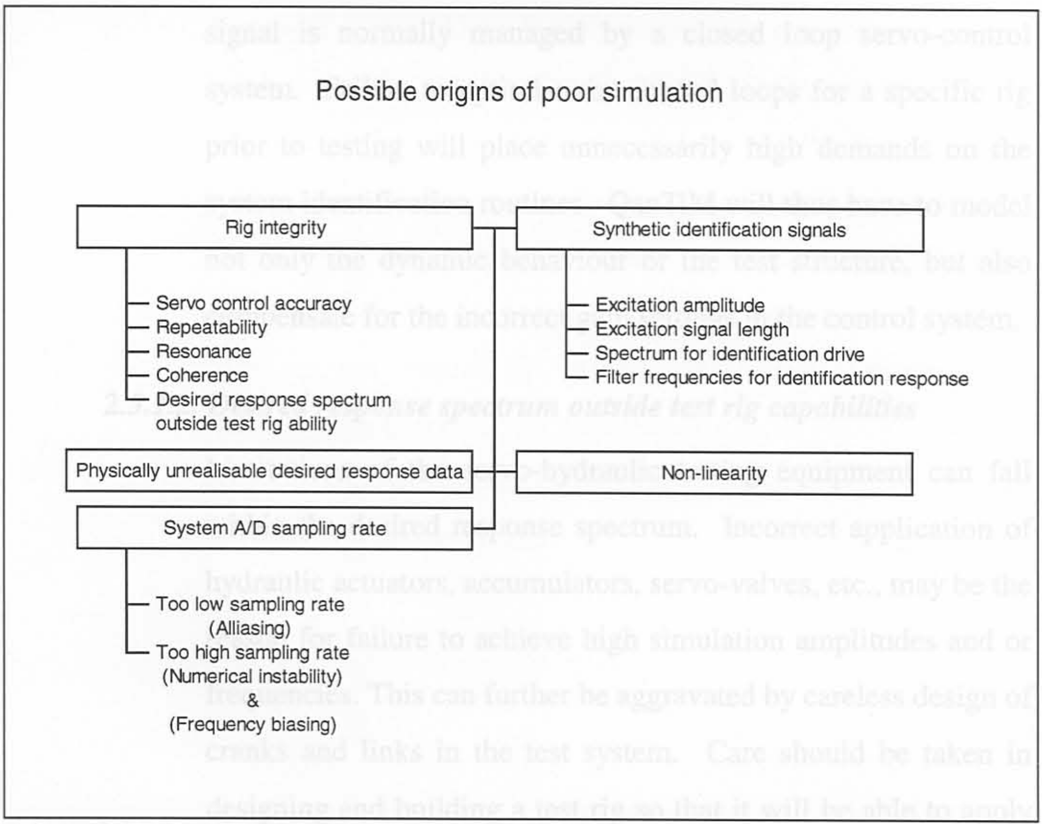

Figure 2.1: Possible causes of inaccurate simulation

The origins of poor simulation as suggested in Figure 2.1 were derived from practical experience on various single and multi-axial servo-hydraulic test rigs. Although not all of these problems are addressed in this study, proposed research as to their solutions are detailed in Section 2.3.

2.3. Proposed investigation for improved time domain simulation

The reasons for poor simulation are discussed and where applicable, a line of research into the improvement thereof suggested. The framework presented in Figure 2.1 is maintained for this discussion.

2.3.1. Test rig integrity

Poor modelling and simulation are often related to problems concerning the test rig configuration. The most obvious problem, servo-control loop accuracy, is normally easy to rectify. More intricate problems include poor coherence, non-repeatable rig behaviour, etc.

2.3.1.1. Servo-control accuracy

The accuracy with which the actuator can maintain a drive signal is normally managed by a closed loop servo-control system. Failure to optimise the control loops for a specific rig prior to testing will place unnecessarily high demands on the system identification routines. QanTiM will thus have to model not only the dynamic behaviour of the test structure, but also compensate for the incorrect gain settings in the control system.

2.3.1.2. Desired response spectrum outside test rig capabilities

Limitations of the servo-hydraulic testing equipment can fall within the desired response spectrum. Incorrect application of hydraulic actuators, accumulators, servo-valves, etc., may be the reason for failure to achieve high simulation amplitudes and or frequencies. This can further be aggravated by careless design of cranks and links in the test system. Care should be taken in designing and building a test rig so that it will be able to apply the required loading.

2.3.1.3. Repeatability

The time domain modelling routines within QanTiM are not capable of describing, chaotic or stochastic system behaviour. It was thus proposed to develop a method of quantifying rig repeatability prior to system identification. A scheme for finding a repeatability number applicable to response reconstruction with servo-hydraulic test rigs is presented in Section 3.1.

2.3.1.4. Resonance

QanTiM has difficulty in simulating data over areas of system resonance [15][45]. If the resonance is rig related, that is a function of the rig fixtures, actuators, links, cranks, etc., a redesign of the rig is necessary. If however the test specimen shows resonant frequencies within the desired response data, careful modelling is needed to correctly simulate this behaviour. Two methods were proposed to deal with rig resonance namely: split spectra modelling (Section 3.2) and anti-resonance identification (Section 3.3) both these methods attempt to model only the forced response of the rig, thus ignoring the free, or resonant, system behaviour.

2.3.1.5. Coherence

Coherence describes the extent to which the system response is linearly related to the excitation [60]. A high level of coherence between a system's individual input - output pairs simplifies the modelling process. A good design policy implies designing test rigs in which each response transducer is closely correlated to its corresponding actuator. Coherence, as such, is fundamentally applicable to the frequency domain. Accurate coherence calculations are not possible using the short Sections of data common to time domain modelling. A time domain equivalent to coherence may shed some light on many modelling problems.

2.3.2. Physically unrealisable desired response data

For the purpose of service history simulation testing all desired response data should ideally be taken from field measurements done with the same test structure to be used in the laboratory, using exactly the same transducers. This implies that all data will be physically realisable. Some sort of signal processing will however invariably be performed on the field data prior to response reconstruction. This pre-processing of field data may include: low-pass filtering to remove system noise, de-glitching to remove spikes, scaling, removing of DC-offsets, etc. If care is not taken when pre-processing field data, the data could be modified to such an extent that it is no longer characteristic of the response of the system.

2.3.3. Analogue to digital conversion

Computer analysis of measured data invariably requires the use of some analogue to digital conversion system. This step from continuous to discrete time presents the test engineer yet another obstacle: the correct sampling rate. Selecting a too low sampling rate may result in alliasing, and an inaccurate representation of the system responses, which is particularly problematic for fatigue testing where accurate achievement of load cycle turning points is imperative. On the other hand, a too high sampling rate can have detrimental effects on the numerical stability of system identification algorithms. It is hypothesised that an optimum relationship exists between the system sampling rate, the simulation bandwidth and the dynamic model order.

2.3.4. Synthetic identification signals

Synthetic excitation signals are generated from a prescribed power spectral density (PSD) function and conceptually constitute pseudo random, shaped white noise. These signals are sent simultaneously to all actuators, thereby exciting the entire test rig, while at the same time recording the responses from the same transducers used during field measurements. This input - output data is then used to calculate a time domain model for the entire test system.

2.3.4.1. Identification drive spectrum

The shape of the PSD function from which the identification drive signals are generated adversely influences the accuracy of the model. Investigation into an optimum excitation spectrum for a specific rig would prove of immense value. A method was devised to calculate an excitation PSD, which would minimise the effect of system resonance and optimise coherence for MIMO systems. This automatic PSD generation function is described in Section 3.3.

2.3.4.2. Identification signal length

The length of the identification signal proved relatively insignificant to the simulation results. Identification signals in the region of 15 ~ 30 seconds are typically used. It is however proposed that an optimal signal length be calculated automatically. Such an optimal identification signal length is likely to be a function of the system sampling rate, the simulation bandwidth and the number of channels.

2.3.4.3. Filter frequencies for identification responses

The identification response signal is invariably filtered in a pre-processing routine prior to system modelling. The effect of filtering and filter frequencies of the identification response signal is addressed in Section 3.4.

2.3.5. Non-linear modelling capabilities

All commercially available response reconstruction packages, including QanTiM are limited to linear modelling techniques. The ability to model non-linear system behaviour could have a notable effect on accuracy and general applicability of the package. Non-linear behaviour in the system could be due to geometrical non-linearity, tyre characteristics, leaf springs, rubber and other synthetic elements, friction, backlash, etc. A comprehensive investigation into implementation of non-linear modelling techniques to complement the existing linear software package is included in Part II of this study.

2.4. Research summary

Simulation results are not always as accurate as desired, examples of typical simulation problems were presented, and possible solutions suggested. The research into implementation of these solutions can be divided into three categories:

1. Problems that can be solved by accurate engineering decisions concerning test rig design, servo-control accuracy, transducer type and placement, etc.
2. Problems to which solutions can be found empirically through research on various practical test rigs. These include identification parameters, pre-processing of desired response data, repeatability quantification and sampling rates for optimal numerical stability and modelling sensitivity.
3. Non-linear modelling: Investigation concerning the implementation and application of non-linear modelling capabilities within the existing system.

Not all the solutions suggested in Section 2.3 are addressed in this thesis. The issues, which are addressed, correspond to Categories 2 and 3 above, and are discussed according to Table 2.1.

Table 2.1: Research summary

PART I Empirical research for improved linear simulation		PART II Investigation into the possible implementation of non-linear response reconstruction	
	Section:		Chapter:
Repeatability quantification	3.1	Linear background	4
Split spectra modelling	3.2	Non-linear system identification	5
Optimal identification drive	3.3	Application of non-linear system identification and response reconstruction	6
Pre-processing of identification data. (filtering, de-trending, etc.)	3.4		