

## ITERATE CONTROL TECHNOLOGIES

Servo-hydraulic component testing continues to be widely used across a variety of industries, not only for durability analysis but also to facilitate optimum system design prior to large scale manufacture. Use of such systems is well established in the materials testing and automotive sectors, particularly in Europe and the USA and there exist significant new business opportunities within the emerging economies of India and China.

A requirement for most systems is that the hydraulic actuators are controlled in such a way that desired reference profiles (of force, displacement, strain etc.) are accurately replicated at specific locations on the test specimen or structure. Depending on the application, the nature of the reference profile can vary and ranges from simple sinusoidal signals to complex waveforms obtained from in-service measurements. Typical of this latter requirement is illustrated in the figure below where the actuators must be driven to replicate accelerations, on the vehicle body, that were previously measured for a specific road surface.



Motor Vehicle Testing

This problem of waveform replication represents a very demanding problem that cannot, in most cases, be solved with standard three-term actuator controllers. As a result, an alternative methodology is widely utilised whereby the controller command signal is modified in a iterative series of experiments until the measured signal on the specimen closely matches that required. Once

the command or drive signal is obtained in this way the test proceeds for the required number of cycles.

All of the major suppliers of servo-hydraulic test equipment offer controller design software that can perform this iterative approach to drive file generation. Examples include MTS with RPC (remote parameter control), Instron's TWR (time waveform replication), a joint venture with LMS and FasTest from FCS. The estimated value of the installed European market alone for such software is thought to be in excess of £5m. Despite the variety of software packages available, all are based on the same fundamental approach that utilises the "inverse algorithm" that was developed by Engineers at General Motors in the 1970's.

The inverse algorithm operates by correcting the drive signal on each iteration by an amount that results from filtering the error from the previous iteration, using an inverse dynamic model of the test system and specimen. Despite its popularity, the inverse algorithm is known to perform poorly when the dynamic model cannot be obtained to a high degree of accuracy (due to non-linearity in the specimen, for example) or when there is significant structural resonance present. Such cases are not isolated and with the increasingly complex dynamics of modern materials and composite structures, the limitation of existing iterative control software packages is continually being highlighted.

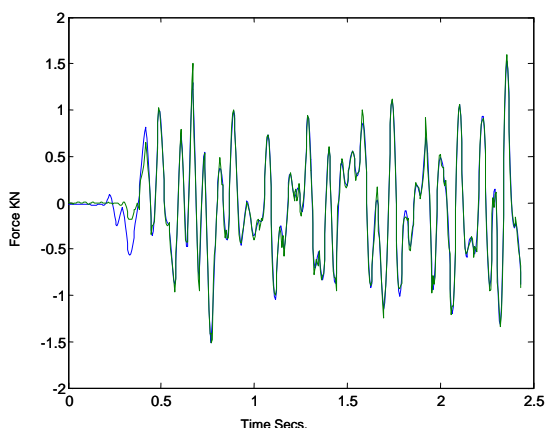
As a result of such deficiencies, an alternative approach has been developed that exploits research activity within the Department of Automatic Control and Systems Engineering at the University of Sheffield. A number of new and very powerful iterative control methods have been developed that have been shown both theoretically and experimentally to have superior performance to the standard solution. A particularly powerful method is a generalised algorithm (that is the subject of several patent applications) that allows a

trade-off to be made between the exceptional robustness properties of an optimal gradient method and the good convergence speed of the inverse algorithm.



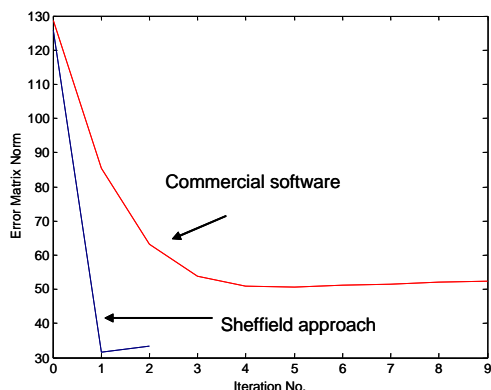
Five Channel Test Rig

A number of application studies have demonstrated the exceptional performance of the method. The figure above shows a five channel rig testing an automotive body section. The requirement was to replicate service loads acquired from a vehicle being driven over a cobbled road surface.



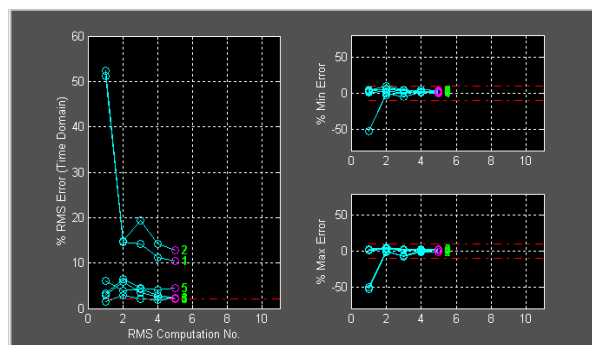
Desired and Measured Force

The result of the force response in channel one after *one iteration* of the generalised algorithm together with the desired force is shown above. This performance can be put into context by comparing with the error evolution of the standard inverse algorithm over a number of iterations.



### Error evolution for all channels

The second example demonstrates the significant advantage of the generalised algorithm in the presence of structural resonance. The system is a multi-axis shaking table used for earthquake simulation. With a resonant payload, the learning gain for the inverse algorithm has to be selected to be relatively small in order to obtain convergence.



Error Evolution – Generalised Algorithm

The generalised algorithm, however, obtains a good solution after only five iterations. The weighting on a problematic channel was also modified on the third iteration, the improvement in which is clearly shown in the figure above.

These new algorithms are particularly suited to control problems in dynamic testing. They are available commercially through Iterate Control Limited and have the advantages of robustness, flexibility and ease of use over existing solutions. In a number of application studies, the potential to improve accuracy while reducing test set-up times has clearly been demonstrated. The power and unique nature of the method has already been recognised by the major suppliers and a number are evaluating a beta version of the software with a view to incorporating within their existing product ranges.

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