Instrumentation
And
RPC Road Simulation
Instrumentation Options

• Specimen as transducer
  – Instrument locations on the vehicle chassis and components to measure forces using strain gages
  – Use accelerometers and displacement transducers for vertical motion
  – Modify existing components to assist in acquiring required data
  – Come up with a complete new concept and design to do what you need.

• Wheel Force Transducer
  – Integrate a special purpose rotating Wheel Force Transducer into the wheels for multiaxial force measurement
• RPC Control Transducers

Strain gages

Accelerometers
- Correlation Gages
**Specimen as Transducer**

- Apply strain gages to the forks, frame, and swing arm to measure forces transmitted into the chassis
  - Two sets of 4 gages (one set on each fork arm) measure 5DOF at forks
  - Gages are summed and differenced to get individual forces
Front Suspension Instrumentation

- Front Suspension Motion
  - Left AccZ
  - Left AccX
  - Left DspZ
  - Right AccZ
  - Right AccX
  - Right DspZ
Swing Arm Instrumentation

- Swingarm DspZ
- Swingarm AccZ
- Swingarm AccX

Rear Suspension Motion
Active Rider Instrumentation

Handlebars
- Left Fz
- Left Fx
- Right Fz
- Right Fx
- Left AccZ
- Left AccX
- Right AccZ
- Right AccX

24 Ch Data Recorder
Somat eDAQ
Added Mass 16 lb

Footpegs
- Left Fz
- Left Fx
- Right Fz
- Right Fx
- Left AccZ
- Left AccX
- Right AccZ
- Right AccX

Driver interface forces measured to control Active Rider
Custom Solutions
To fit your needs
I need to test an exhaust system,
But how?
The Specimen
Need to measure system forces and motions
Load Cell Final Design

4 units manufactured for Customer project

MTS Proprietary Information
Load Cell usage

- Mount between each Mass in Exhaust system.

- MTS Proprietary Information
Displacement Environment characterization

• Develop 3 axis displacement device
• Use for flex-pipe displacement measurement
• Use for engine position measurement

• MTS Proprietary Information
Leaf Arm usage flex pipe

- MTS Proprietary Information
Leaf Arm usage Engine

- MTS Proprietary Information
Single MAST table system
Dual MAST configuration
MAST with Hanger point excitation
Example of a full car data acquisition project
Trail Arm Realization
Biaxial Requirement
Biaxial Design

• Shear Bridges on Machined Cylindrical Sections
• Eliminates contact point calibration dependency of bending bridge design approach.
Always check clearance!
Installation
Intercept 2 forces and 2 moments at body attach
Assembly
Front Suspension Re-Installation
Data Acquisition set-up
Data Acquisition Unit Installation
Power Install
Final Touches (stone shields, heat shields)
Ready For Road Test
Spinning Wheel Integrated Force Transducers

- Light-weight transducer for easier, faster, less expensive data acquisition and road simulation testing
- Sizes available to accommodate micro vehicles, compact to mid-sized cars, light to medium trucks, and large trucks
- Strain gauge-based transducer.
- Measures Forces and moments at center of the transducer
- Transducer spins with wheel.
- Output is 3 forces and 3 moments (Fx, Fy, Fz, Mx, My, Mz) in non-rotating vehicle coordinate system.
## All SWIFT Models

<table>
<thead>
<tr>
<th>Product</th>
<th>Material</th>
<th>Assembly Weight (lbs.)</th>
<th>Half Axle Durability Rating (lbs.)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWIFT 10</td>
<td>Al</td>
<td>12.8</td>
<td>606</td>
</tr>
<tr>
<td>SWIFT 10</td>
<td>Ti</td>
<td>14.3</td>
<td>1984</td>
</tr>
<tr>
<td>SWIFT 20</td>
<td>Al</td>
<td>20.7</td>
<td>965</td>
</tr>
<tr>
<td>SWIFT 20</td>
<td>Ti</td>
<td>24.2</td>
<td>1580</td>
</tr>
<tr>
<td>SWIFT 30</td>
<td>Al</td>
<td>28.9</td>
<td>1460</td>
</tr>
<tr>
<td>SWIFT 30</td>
<td>Ti</td>
<td>50</td>
<td>2,400</td>
</tr>
<tr>
<td>SWIFT 40</td>
<td>Al</td>
<td>70</td>
<td>2700</td>
</tr>
<tr>
<td>SWIFT 40</td>
<td>Ti</td>
<td>80</td>
<td>5,100</td>
</tr>
<tr>
<td>SWIFT 50 GLP</td>
<td>Ti</td>
<td>211</td>
<td>9,000</td>
</tr>
<tr>
<td>SWIFT 50 GLP</td>
<td>SS</td>
<td>247</td>
<td>14,500</td>
</tr>
</tbody>
</table>
## SWIFT™ Saves Time

<table>
<thead>
<tr>
<th>Conventional Instrumentation</th>
<th>Wheel Force Transducers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads analysis</td>
<td>Install transducers</td>
</tr>
<tr>
<td>5-10 days</td>
<td>½ day</td>
</tr>
<tr>
<td>Component removal</td>
<td>Route wiring</td>
</tr>
<tr>
<td>2 days</td>
<td>½ day</td>
</tr>
<tr>
<td>Component modification</td>
<td>Set up instrumentation</td>
</tr>
<tr>
<td>5-10 days</td>
<td>and calibrate</td>
</tr>
<tr>
<td>Vehicle re-assembly</td>
<td>½ day</td>
</tr>
<tr>
<td>2 days</td>
<td></td>
</tr>
<tr>
<td>Route wiring</td>
<td>Less than 2 days</td>
</tr>
<tr>
<td>2 days</td>
<td></td>
</tr>
<tr>
<td>Install data acquisition</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td>Calibrate</td>
<td></td>
</tr>
<tr>
<td>2-4 days</td>
<td></td>
</tr>
</tbody>
</table>

Up to one month (or more)
Wheel Force Transducer System

The Wheel Force Transducer gives the bridge output signals and the angular position through a slip ring and encoder.

The Transducer Interface box converts these signals to the non-spinning vehicle coordinate system.

The three force and three moment signals are output from the TI in the form of +/- 10 V analog signals.
What do we do with all this data?
Introduction to RPC
Road Simulation

MTS Systems Corporation
RPC Introduction

- What is Remote Parameter Control?
- The RPC Process
- Why is RPC Necessary?
- RPC Uses & Applications
- Advantages of RPC Testing
What is Remote Parameter Control?

- Remote Parameter Control (RPC) is an advanced simulation technique used to repeatedly replicate and analyze “in service” vibrations and motions of a specimen using a dynamic mechanical system in a controlled laboratory environment.

  *e.g. Accelerometer*

2. PARAMETER

3. CONTROL
Control of
- Amplitude Distributions
- Spectral Densities
- Multi-axial Phase Relationship
Why use Remote Parameter Control?

• The fundamental driving force of why we use RPC is to reproduce the damage caused by the road in a controlled environment.
RPC Introduction

• What is Remote Parameter Control?

• The RPC Process

• Why is RPC Necessary?

• RPC Uses & Applications

• Advantages of RPC Testing
How does RPC work?

- The RPC process follows a number of key steps which we will discuss in the next slides.

- But First, think about this problem:
  - How do you reproduce road loads in a test lab?
  - How do you produce the correct loads AND motions in real-time?
**Step 1: Record Road or Service data**

- **Step 1 – Record Road Data**
  - Before we can reproduce failures in the lab we need to understand the loading a component experiences. To do this we need data.
  
  - Road data typically comes from the Proving Ground where events are specifically designed to induce high dynamic loads into the vehicle.
The RPC Process – Step 1

- What do we need to record Road Data?
  - Before:
    - Identify primary components and locations for instrumentation
    - Instrument vehicle with appropriate transducers
    - Configure and checkout data acquisition system
    - Perform Calibration
  - During:
    - Monitor transducer responses for overloads and loss of signal
    - Collect multiple runs and document acquisition
  - After:
    - Validate and Archive Raw data
    - Move on to Step 2.
The RPC Process – Step 1

• Equipment:

Instrumentation

Data Acquisition System
The RPC Process – Step 1

- Software:

**RPC Pro Acquire**

- Road Load Data Validation and Anomaly Detection

**RPC Pro Reporting**

- Report Generation Tools
Step 2 – Data Editing & Analysis

- In the previous step multiple events, passes and conditions will have been collected with many channels.
- If all this data were used for a simulation test, the test would take too long.
- The goal of editing is to shorten the test time while still retaining as much damaging content as possible.
The RPC Process – Step 2

• What do we need to edit data?

  – Before:
    • Validate “quality” of raw data
    • Select Road Profiles for simulation
  – During:
    • Optimize individual profiles via editing process
  – After:
    • Confirm Edit-to-Raw correlation is as required
The RPC Process – Step 2

• Tools:

Fatigue Life Calculation

\[ D = \sum \frac{ni}{Ni} \]

RPC Pro Analyze Application

Fatigue Analysis Tools

Cycles to Failure

Stress Amplitude
Step 3: Measure System Model

- Step 3 – Measure System Model
  - The previous steps can be considered “data preparation steps”
  - The System Modeling step is the first time we will use the test article with the test equipment.
  - The purpose of the System Model is to define the relationship of inputs to outputs.
    - The inputs are the rig actuators – “drive”
    - The outputs are the specimen transducers – “response”
The RPC Process – Step 3

• What do we need to measure a system model?

  – Before:
    • Install specimen in test fixturing
    • Confirm transducer feedbacks (same channels as step 1)

  – During:
    • Excite system with random noise and collect responses

  – After:
    • Evaluate system model
The RPC Process – Step 3

• What are the key elements of a “good” system model?

  – Objective:
    • Create a system model that uniquely defines all required simulation degrees of freedom with minimal cross-talk and with the minimum number of transducers

  – Ideal System Model:
    • Each drive channel (input) independently defined by a single response channel
    • No cross-coupling between responses
    • Highly linear response across the simulation frequency of interest
The RPC Process – Step 3

- Modeling the system
  - The System Model is a Frequency Response Function (FRF)
    - It tells us the relationship of outputs to inputs across the frequency band. In other words for a given input we can calculate the output.

\[ \text{Input (Drive)} \quad \xrightarrow{\text{FRF}} \quad \text{Output (Response)} \]

- Now ask yourself the question: “What do we know and not know?”
The RPC Process – Step 3

- Modeling the system – what do we know?

- Problem: We do not know what the input to the test rig is in order to reproduce the output seen on the road.
The RPC Process – Step 3

• Tools:

- Tri-axial Motor Mount testing
- RPC Pro Model Application
- Test System
- Data Acquisition System
Step 4: Iterations

• Step 4 – Iterations
  – The System Modeling and Iteration steps are commonly referred to as “Drive File Development”

  – This step consists of two parts:
    • Initial drive estimation
    • Iterations
The RPC Process – Step 4 (Part 1)

- Iterations: initial drive file estimation
  - Going back to the previous problem:
    - We do not know what the input to the test rig is in order to reproduce the output seen on the road.
    - The solution is as follows:

\[
\frac{1}{\text{FRF}}
\]

\[
\text{Input (Drive)} \rightarrow \frac{1}{\text{FRF}} \rightarrow \text{Output (Response)}
\]
The RPC Process – Step 4 (Part 2)

- Iterations
  - The iteration process involves:
    1. Playing out a drive to the test rig
    2. Collecting the response
    3. Calculate the error between the response and the desired data
    4. Use the error to update the next drive file
  - In reality the component and test system is a non-linear system. Iterations are used to incrementally correct the drive file since a “one-shot” prediction of the drive is not possible – and if you get it wrong….
The RPC Process – Step 4 (Part 2)

- Iterations – example drives
Simulation results are typically evaluated in the time, frequency, and statistics domains; often times fatigue is also used.
The RPC Process – Step 4

• What do we need to iterate road data?

  – Before:
    • Evaluate System Model and prepare inverse FRF
  – During:
    • Monitor convergence in time, frequency and statistic domains
  – After:
    • Define the final drive
    • Collect additional correlation data is required
The RPC Process – Step 4

• Tools:

- Tri-axial Motor Mount testing
- RPC Pro Simulate Application
- Data Acquisition System

Test System
The RPC Process – Step 5

Step 5: Durability Test

- Step 5 – Durability Test
  - After iterating each of the individual road profiles a durability test can be constructed
  - The test is created to replicate the durability schedule that would also be conducted at the track
  - Monitoring will be used to identify when failures are imminent
The RPC Process – Step 5

- Durability Test: defining the test sequence
The RPC Process – Step 5

• Durability Test: monitoring test sequence

Providing accurate information to the user:

• Current status of test (running, aborted, etc)
• Control Panel
• Test time remaining
• Elapsed time
• Current drive and sequence
The RPC Process – Step 5

- Durability Test: monitoring test sequence

During a Test — responding to limit trips:

- Type of limit (Max Lower Limit)
- File and channel limit occurred on (belgian_8_fin_rsp – ch3)
- Value of limit and parameter which tripped the limit (14.5, 13.25)
The RPC Process – Step 5

- What do we need to run a durability test?
  - Before:
    - Construct durability test sequence
    - Define monitoring
  - During:
    - Monitor specimen load changes
    - Inspect specimen for cracks and failures
    - Document Test incidents
  - After:
    - Create test report
    - Archive test data
The RPC Process – Step 5

- **Tools:**
  - Tri-axial Motor Mount testing
  - Test System
  - RPC Pro Test Application
  - RPC Pro Data Manager
  - Data Acquisition System
RPC Introduction

• What is Remote Parameter Control?

• The RPC Process

• Why is RPC Necessary?

• RPC Uses & Applications

• Advantages of RPC Testing
Why is RPC necessary?

• Summary:
  – Necessary to convert a Response signal (i.e. the Road) into a Drive signal (i.e. actuator command) during the RPC process
  – Necessary to control the Drive in non-linear systems so that it reproduces the Desired Response
  – Necessary to Analyze data in a number of different formats (Time Histories, Frequency, Statistics, Fatigue)
  – Need to play back Drive signals (Durability)
Requirements for RPC Testing

• Summary:
  – An Instrumented Specimen
  – Data Acquisition System
  – A Servo Hydraulic Test Rig
  – An MTS RPC Computer System
    • Component RPC Pro
    • RPC Pro
  – Trained Staff
  – Scheduling Must Include Adequate Time
RPC Introduction

• What is Remote Parameter Control?

• The RPC Process

• Why is RPC Necessary?

• RPC Uses & Applications

• Advantages of RPC Testing
RPC Uses and Applications

Evaluate Complete Structure
Durability

329 Road Simulator

Evaluate Component Structure
Durability or Performance Characteristics

Tri-axial Motor Mount testing
RPC Uses and Applications

Evaluate Noise & Vibration, and Squeak & Rattle Phenomena

4 Poster NVH Testing

Evaluate Component Noise & Vibration

High Frequency MAST
RPC Uses and Applications

Body, Chassis/suspension & body-mounted components durability testing

**4 Poster Durability Testing**

Durability testing of plastic components at low temperatures

**4 Poster Environmental Chamber Testing**
Durability Testing/ Vibration Testing of a variety of components or assemblies

Engine Mounts, Radiator, Battery box etc
RPC Simulation Software

• The MTS family of Simulation Software
  – RPC Pro & Component RPC Pro
  – MTS has over 1000 installed seats of RPC software
RPC Simulation Software

• Component RPC Pro
  – Less complex road simulation application
  – Designed for new users
  – Focus on simplicity and Ease of Use
  – Cost effective reduced feature toolset
RPC Simulation Software

- Component RPC Pro
RPC Simulation Software

- RPC Pro
  - Complex road simulation and analysis application
  - Fatigue Analysis and Signal Processing
  - State of the Art patented simulation technologies:
    - Adaptive Inverse Modeling
    - Effective Road Profile Control
    - Control Band Prediction
RPC Simulation Software

- RPC Pro
RPC Introduction

• What is Remote Parameter Control?

• The RPC Process

• Why is RPC Necessary?

• RPC Uses & Applications

• Advantages of RPC Testing
Advantages of RPC Testing

- Lab Testing verses Field Testing
  - Repeatability of test system versus proving ground
  - Takes less time and is more cost effective
  - Can test components rather than the entire system
  - Can collect more data
  - Progression of damage is easier to observe
Advantages of RPC Testing

• RPC Testing verses other Testing
  – Accurate Reproduction of Amplitude Distributions
  – Can Maintain the Correct Phase between Channels
  – Iterative solution to control non linear systems
  – Analysis of data can be carried out both in multiple domains
Additional
Or
Optional Packages
Operating Deflection Shapes (ODS)

- Allows designer to visualize and analyze structural deformation under actual loads
- Correlates computer based multi-body dynamics models to "real world" prototype motorcycle
**ODS Procedure**

- Define the geometry
- Locate accelerometers
- Collect acceleration data under “real loads”
- Link accel measurements to geometry
- ODS analysis
Locate Accelerometers

- At points (nodes) established in previous step
Collect Acceleration Data Under “Real Loads”

- Tire coupled Simulator
- Spindle Coupled Simulator
Operating Deflection Shape Wizard - Step 6 of 7

To preview an operating deflection shape, simply drag the cursor to the frequency of interest, save the shape, push Store.

Prototye Motorcycle
Mode at 25.75 Hz
ODS Benefits

• Actual time histories used as forcing functions
  – Structures exhibit realistic responses
• Critical areas susceptible to fatigue damage can be identified early
  – Facilitates monitoring during a durability test.
• Structural deformations can be easily visualized with the animation feature.
  – Communications between test engineering and design engineering functions are enhanced.
• Structural deformation behavior can be done before a running engine is available
  – Shortens product development time
Ride Comfort- Before and Now

• In the past, most ride comfort analysis used trial and error procedures
• Results were variable and dependent upon:
  – Rider (training, health, ...)
  – Time of day
  – Weather
  – Limited repeatability of road inputs
• Now, ride comfort analysis is
  – Objective
  – Accurate
  – Repeatable
Ride Comfort Procedure

- Locate accelerometers
- Collect acceleration data under “real loads”
- Apply weighting filters
- Calculate ride number
Locate Accelerometers

Road Input

Road Input
Locate Accelerometers
Collect Acceleration Data Under “Real Loads”

- Tire Coupled Simulator
Apply Weighting Filters

- Human body has greater sensitivity to vibration at certain frequencies
- Weighting filters compensate for sensitivities
- Many weighting filters are proprietary due to competition
Calculate Ride Number

- NASA Model, per Technical Paper 2299, 1984
- ISO 2631
- User Defined Weighting
  - for NASA 2299
  - for ISO 2631
Calculate Ride Number

The box below contains the results of the ride comfort estimation. Preview the results here. Move on to the next step to print the report or to save it.

<table>
<thead>
<tr>
<th>Overall Ride Number</th>
<th>3.91</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>1.49</td>
</tr>
<tr>
<td>Lateral</td>
<td>1.56</td>
</tr>
<tr>
<td>Fore/aft</td>
<td>0.71</td>
</tr>
<tr>
<td>Roll</td>
<td>1.04</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary Ride Number</th>
<th>2.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>0.78</td>
</tr>
<tr>
<td>Lateral</td>
<td>0.94</td>
</tr>
<tr>
<td>Fore/aft</td>
<td>0.49</td>
</tr>
<tr>
<td>Roll</td>
<td>0.39</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary Ride Number</th>
<th>3.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>1.36</td>
</tr>
<tr>
<td>Lateral</td>
<td>1.43</td>
</tr>
</tbody>
</table>
Analyze Affect on Handling

- Analyze change in response due to changes in suspension settings
- Evaluate suspension’s effect on handling
Benefits

• Objectivity
• Repeatability
• Measurement sensitivity
• Shock absorber “aging” for long-term ride comfort prediction
## Product Development Cycle

<table>
<thead>
<tr>
<th>Time</th>
<th>Design</th>
<th>Proto 1</th>
<th>Field Test</th>
<th>Redesign</th>
<th>Proto 2</th>
<th>Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Test</td>
<td>Design</td>
<td>Proto 1</td>
<td>Lab Test</td>
<td>Redesign</td>
<td>Proto 2</td>
<td>Lab Test</td>
</tr>
<tr>
<td>Lab Test</td>
<td>Design</td>
<td>Proto 1</td>
<td>Lab Test</td>
<td>Lab Test</td>
<td>Opportunity</td>
<td></td>
</tr>
<tr>
<td>Virtual Test</td>
<td>Design &amp; Virtual Test</td>
<td>Proto</td>
<td>Lab Test</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Opportunity** = **Lower Development Cost**  
**Opportunity** = **Shorter Development Time**
Take Your Design Validation...

From the Test Track... To the Test Lab... To the Virtual Test Lab
Integrated Products

• Virtual Test Lab
  – Designed for the Analytical-Design Process
  • Traditional Testing and Validation Process
• Empirical Dynamic Model (EDM) - “BlackBox”
  – Mathematical Representation of Component Characteristics Requiring Empirical Data (Elastomer, Shock Absorber, Tires)
Virtual Test Lab

• Motorcycle Simulation
Virtual Test Lab

Initial ADAMS motorcycle model generation

Virtual 2-poster test for ADAMS model validation

Final validated ADAMS model

Lab 2-poster and suspension tests for ADAMS model validation

Build new Prototype part

Prototype lab Durability test

Final design

Instrumentation and Road Data collection

compare virtual physical redesign

Data Analysis and Edit

Milestones
**Vehicle Dynamics - Virtual and Physical Testing**

No

Satisfied

Yes

PROVEN RESULTS

Practical seminars for greater testing accuracy
Empirical Dynamic Model

- Physical Testing Generates Data for Model Creation
  - FEA
  - Black Box, Characteristic, and Concept Model
lab test to virtual model correlation

- Plot of virtual 2-poster load and lab 2-poster results for shock linkage load

![Linkage Loads Graph]

Measured load

Predicted load
Virtual Test Lab - Benefits

• Minimize or eliminate the number of trips to the test track
  – Sensors can be repositioned with greater confidence in results

• Minimize the number of trips to the test lab
  – More tests can be executed on different test articles
  – More data can be obtained
  – Information not received because of time constraints will now be available

• Component tests defined from isolation of loads executed on system model
  – Information is generated for tier 1 suppliers