An Introduction to Fatigue Testing Equipment, Test Setup & Data Collection

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Servohydraulic Sales Specialist & Market Manager - Instron
Themes..

• Certainty of Measurement
• Repeatability of Measurement
• Safety & Legislation
• Usability & User Experience
Things to cover...

• Fatigue Testing Basics:
  • Why Servo-Hydraulic?
  • The key components of a servo-hydraulic system.
  • The working principle behind an actuator.
  • Factors which effect performance.
  • Sensors and control.
  • User Interfaces.

• Test Setup & Data Collection:
  • Grips and fixtures for fatigue.
  • Data collection and processing.
  • Advancements.
  • Alternatives to Servo-Hydraulics for fatigue
Servohydraulic System Setup

- Actuator & LVDT
- Manifold + Servo-Valve
- User Interface
  - PC/Software
- Load Frame
- Load Cell
- Test Area
- Hydraulic Power Unit (HPU)
- Flexible Hoses
- Controller

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Why Servohydraulic (SH)?

• Low compressibility allow for a stiff and dynamic actuator system.
• Very smooth and efficient for linear movement.
• Provide a ‘compact’ way of achieving high forces.
• Versatile performance just by configuring the system components.
• Reliable test machines which can be in use for 30 years or more!
• Good for Fatigue testing, particularly metals, where we want to test many cycles usually at high frequency.
Standard SH System

HYDRAULICS AND PERFORMANCE

Hydraulic Power Unit -> Hydraulic Hoses -> Manifold -> Servo-Valve -> Actuator

APPLICATION SOFTWARE

Instron Software <-> Set Point Command <-> Sensor Data

SENSORS AND CONTROL

8800 Controller
- Force
- Position
- Loadcell
- LVDT

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Hydraulic Power Supply

• Responsible for providing High pressure (207 bar) oil for the test system
• Characterised mainly by the flow of oil they can provide in litres/ min.
• Pressurised fluid energy generates heat – requires cooling
• Power Consumption – 3 phase

• Notes:
  • Cooling - Air or Water
  • Acoustic Attenuation
  • Pressure Accumulation
  • Flexible Hoses
  • Filtration & Oil Maintenance
Actuator, Servo-valve & Manifold

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Hydraulic Actuators

- A simple piston with two chambers.
- Actuator movement is caused when the oil pressure in the two chambers is not equal.
- Controlling the flow/pressure of oil in each chamber controls the actuator movement.
Bearing Types

Labyrinth or ‘Plain’

• Standard for many suppliers
• Mechanical Movement draws lubrication in
• Can be damaged by sideloads!

Hydrostatic

• Uses 4 ‘pads’ of hydraulic oil keep the piston rod central and lubricated inside the bearing.
• Increases in sideload result in increased resistance from pressure pads.
• Less friction in the bearing
Hydraulic Manifold

• A hydraulic ‘circuit’ machined from a single block.

• Allows hydraulic components to be attached easily. Most commonly, SVs, Accumulators and Hoses.

• Simplifies build process.
• Reduces build time.
• Gives predictable performance.
Servo-Valves

• Control the quantity and direction of fluid flow into the actuator.
• Controlled by a small electrical voltage generated by controller.
• Characterised by the amount of oil that can flow through them.

‘Big’ (high flow) SVs: Good for high frequency / large amplitude
‘Small’ (low flow) SVs: Better resolution for small amplitudes

• 5 l/min
• 10 l/min
• 20 l/min
• 40 l/min
• 65 l/min

• Dual Servo-Valves!
Hydraulic Actuator Operation

- Manifold
- Piston Rod
- Piston
- Piston Seal
- “Servo-Valve”
- Effective Area
- Bearing Assemblies

Pressurized fluid enters the system through the "Servo-Valve" and is directed to either the piston or the return path. The effective area of the piston determines the force generated.
Achieving Higher Forces & Performance?

*Force = Pressure × Area*

• In our systems we assume the pressure of the oil is constant, normally 207Bar

• If we want to achieve higher forces then we have to increase the ‘effective area’ of the actuator.

• Increasing the piston area means we need more oil flow to maintain the same performance.
Oil Flow, Pressure & Performance

HYDRAULICS AND PERFORMANCE

- To move the actuator quickly, we need more oil flow
  - Oil flow is measured in litres/min e.g. 48l/min HPU
  - Flow can be limited by HPU, hoses, manifold or SV.

- Pressure is measured in Bar/Psi e.g. 207Bar/3000psi HPU
  - We ‘assume’ pressure is constant. We said that we need more piston area to achieve higher forces.
  - When a lot of oil is flowing, pressure drops can occur between the HPU and the actuator.

- Predicting Performance
  - There is a trade off between frequency, amplitude and force!
  - Performance Plot!
Sensors & Control

- Position
- Force
- Strain
- Compliance
- Strain

- LVDT
- Loadcell
- Extensometer
- COD Gauge
- Strain Gauges

System Supply
Application Specific – Analog 0-10V

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**Sensors & Control**

**Digital Control System**
- Expandable or fixed architecture
- Safety circuits

**Signal Conditioning**
- Automatic Transducer recognition & calibration
- Transducer signal conditioning

**Waveform Generation**

**Data Acquisition**
- 5/10kHz

**Control System**
- Closed loop control
- Advanced control techniques
- 5/10kHz loop closure and update

![Diagram of control system](image)
Load Frames

Load Reaction Frame

- Frame designs based on their dynamic load rating
- Frame stiffness is important!
- Actuator position is configurable (base or crosshead)

- **Handset** for test setup and specimen installation
  - Hydraulic crosshead lift – adjust Test space
  - Actuator jog
  - Emergency stop button
Principle of Operation

Hydraulic Pump

Test Frame
Principle of Operation

Hydraulic Pump

Test Frame
Principle of Operation

Hydraulic Pump

Servo Valve & Manifold

Hydraulic Actuator
Principle of Operation

Hydraulic Pump

Servo Valve

Hydraulic Actuator

Control Unit, closed loop control

LVDT feedback

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Principle of Operation

Hydraulic Pump

Loadcell feedback

Servo Valve

Control Unit, closed loop control
Principle of Operation

Extensometer feedback

Hydraulic Pump

Servo Valve

Control Unit, closed loop control

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User Interface - Software

• System Setup Software
  • Sensor Calibration
  • Loop Tuning
  • Sensor Limits

• Live Sensor Feedback

<table>
<thead>
<tr>
<th>File</th>
<th>Live Displays</th>
<th>mm</th>
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<th>mm</th>
<th>0.033</th>
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<tbody>
<tr>
<td>E1000:Position:Track</td>
<td>E1000:Load:Track</td>
<td>kN</td>
<td>0.000</td>
<td>mm</td>
<td>0.000</td>
<td>mm</td>
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<tr>
<td>E1000:Position:Track</td>
<td>E1000:Digital Position:Track</td>
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</table>
Application Software

• Application Specific Software
  • General Purpose Static & Fatigue
  • Fracture Mechanics – da/dN, JIC, KIC, R-Curve, CTOD
  • LCF, TMF etc

• Waveform Generation, Test Control & Monitoring

• Stress-Life or Strain-Life Data

Crack Growth & Fracture Toughness
Servohydraulic System Setup
Test Setup & Data Collection
Grips & Fixtures for Fatigue

- Standard attachments sized for actuator capacity
- Pre-load for reverse stress testing

High Cycle Fatigue (HCF)  Low Cycle Fatigue (LCF)

Alignment Fixture

1000°C Split Furnace

Reverse Stress Pullrods

1000°C Extensometer
Grips & Fixtures for Fatigue

- Fracture Mechanics

SENB Bend Specimen Setup

CT Specimen Setup
<table>
<thead>
<tr>
<th></th>
<th>Test Setup &amp; Run Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Install Appropriate Grips/Fixtures</td>
</tr>
<tr>
<td></td>
<td>- Pre-load (reverse stress)</td>
</tr>
<tr>
<td></td>
<td>- Alignment checks</td>
</tr>
<tr>
<td>2</td>
<td>Calibrate &amp; Balance Sensors - Load &amp; Strain</td>
</tr>
<tr>
<td>3</td>
<td>Install Specimen</td>
</tr>
<tr>
<td>4</td>
<td><strong>Loop Tuning - PID</strong></td>
</tr>
<tr>
<td></td>
<td>- All channels used in the test</td>
</tr>
<tr>
<td>5</td>
<td>Set Test Limits</td>
</tr>
<tr>
<td></td>
<td>- Protect travel of sensors</td>
</tr>
<tr>
<td></td>
<td>- Appropriate for test conditions</td>
</tr>
<tr>
<td>6</td>
<td>Program Test Method</td>
</tr>
<tr>
<td>7</td>
<td><strong>RUN TEST</strong></td>
</tr>
</tbody>
</table>
Live Test Monitoring

- Live graph editing – freedom to edit at any time
- Progress indicators – instant status feedback
Intelligent Data Processing

Raw Data

Enable

Data Processing

Vector of data
Position
Load
Strain
Cycle count

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Intelligent Data Processing

Raw Data

Enable

Data Processing

Trend
Track
Peaks

Discarded Vectors

Vector of data
Position
Load
Strain
Cycle count

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Calculating Additional Test Data

• Additional Calculated ‘channels’

DMA calculations provide multiple outputs, including:

- Loss Angle
- Tan Delta
- E* (Complex Modulus)
- E’ (Storage Modulus)
- E” (Loss Modulus)
- Energy
- Energy Loss
- K* (Dynamic Stiffness)
- K’ (Elastic Stiffness)
- K” (Damping Stiffness)

Material Properties
- Young’s Modulus
- Static Elastic and Plastic Strain
- Elastic Stiffness

Test Parameters
- Velocity
- Acceleration
- Energy Calculations
- Frame Compliance

Data Interpolation/Extrapolation
- Pre-set Point Measurements ‘Point X at Y’
- Contact Point Determination
Advanced Control Modes

- Run tests not previously possible.
- Use calculated channels as control targets
Alternatives to SH Actuator Drive Systems

- **Pneumatic Actuators**
  - Air is very compliant/compressible
  - Limited to static or low force, slow cyclic

- **Resonance systems**
  - Sinusoidal waveforms only
  - Short Stroke
  - Fixed Frequency – capable of high frequency
  - Essentially open loop control

- **Preloaded Ballscrew Actuator**
  - High precision low speed static, slow cyclic

- **Direct Drive Linear Electric Motors**
  - Long stroke
  - Closed loop control
  - Cyclic testing
  - No oil!
Linear Electric Motor Fatigue System

Actuator & LVDT

Load Frame

Load Cell

Test Area

User Interface
  PC / Software

Power Amplifier

Controller

Load Cell

Acoustically Engineered Air Cooling

Test Area

10 kN ElectroPuls E10000

User Interface

Single-Phase Mains Power

Power Amplifier

Low Energy

Controller

Small Footprint

Controller

PC

Power Amplifier

Load Cell

Test Area

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# Drive System Comparisons

<table>
<thead>
<tr>
<th>Drive</th>
<th>Applications</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo hydraulic</td>
<td>HCF</td>
<td>Highly configurable</td>
<td>High Energy consumption</td>
</tr>
<tr>
<td></td>
<td>Static</td>
<td>Tried &amp; tested</td>
<td>Maintenance costs</td>
</tr>
<tr>
<td></td>
<td>LCF &amp; TMF Fracture</td>
<td>Long life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5kN to +10MN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pneumatic</td>
<td>Low Force</td>
<td>Low cost</td>
<td>Air is compliant/compressible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clean &amp; quiet</td>
<td>Control challenges</td>
</tr>
<tr>
<td>Resonance Drive</td>
<td>HCF</td>
<td>Low Energy consumption</td>
<td>Short stroke</td>
</tr>
<tr>
<td></td>
<td>Fracture Sinusoidal a</td>
<td>Very high frequency</td>
<td>Fixed frequency</td>
</tr>
<tr>
<td></td>
<td>only</td>
<td></td>
<td>Low accuracy</td>
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<tr>
<td></td>
<td>&lt;1MN</td>
<td></td>
<td>Sine waveforms only</td>
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<tr>
<td>Direct Drive</td>
<td>LCF</td>
<td>High Precision</td>
<td>Limited to slow speed tests only</td>
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<tr>
<td>Servo Electric Ball</td>
<td>TMF</td>
<td>Slow Speed Control</td>
<td></td>
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<tr>
<td>Screw</td>
<td>Static</td>
<td>Low Energy Consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;250kN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Drive</td>
<td>HCF</td>
<td>No Oil</td>
<td>Low force</td>
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<tr>
<td>Linear Electric Motors</td>
<td>Static</td>
<td>Low maintenance</td>
<td>Control challenges</td>
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<td>Fracture</td>
<td>Quiet</td>
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<tr>
<td></td>
<td>&lt;15kN</td>
<td>Easily relocated</td>
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Wrap Up..

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Questions?