

***TYPICAL SAMPLE TRAINING
MATERIAL (Edited)***

***R-149 SHAKE TABLE
TRAINING***

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R-149



TRAINING MODULES

M1; SYSTEM OVERVIEW (MON 9:30-11:30)

**M2: DIGITAL DATA ACQUISITION, ANALYSIS, AND CONTROL
(MON 2:30-4:30)**

**M3: SERVO HYDRAULIC PUMP, MANIFOLD, ACTUATOR AND
SERVO CONTROLLER (TUE 9:30-11:30)**

**M4: DATA PHYSICS DIGITAL CONTROLLER/PC AND SPECTRUM
SOFTWARE (TUE 2:30-4:30)**

M5: SYSTEM SAFETY AND MAINTENANCE (WED 9:30-11:30)

**M6-7: TYPICAL TESTING PROCEDURES AND HANDS ON TABLE
USE (WED 2:30-11:30 AND THU 9:30-11:30)**

**M8: REVIEW AND SELECTED REQUESTED TOPICS
(THU 2:30-4:30)**

Module 1

SYSTEM OVERVIEW

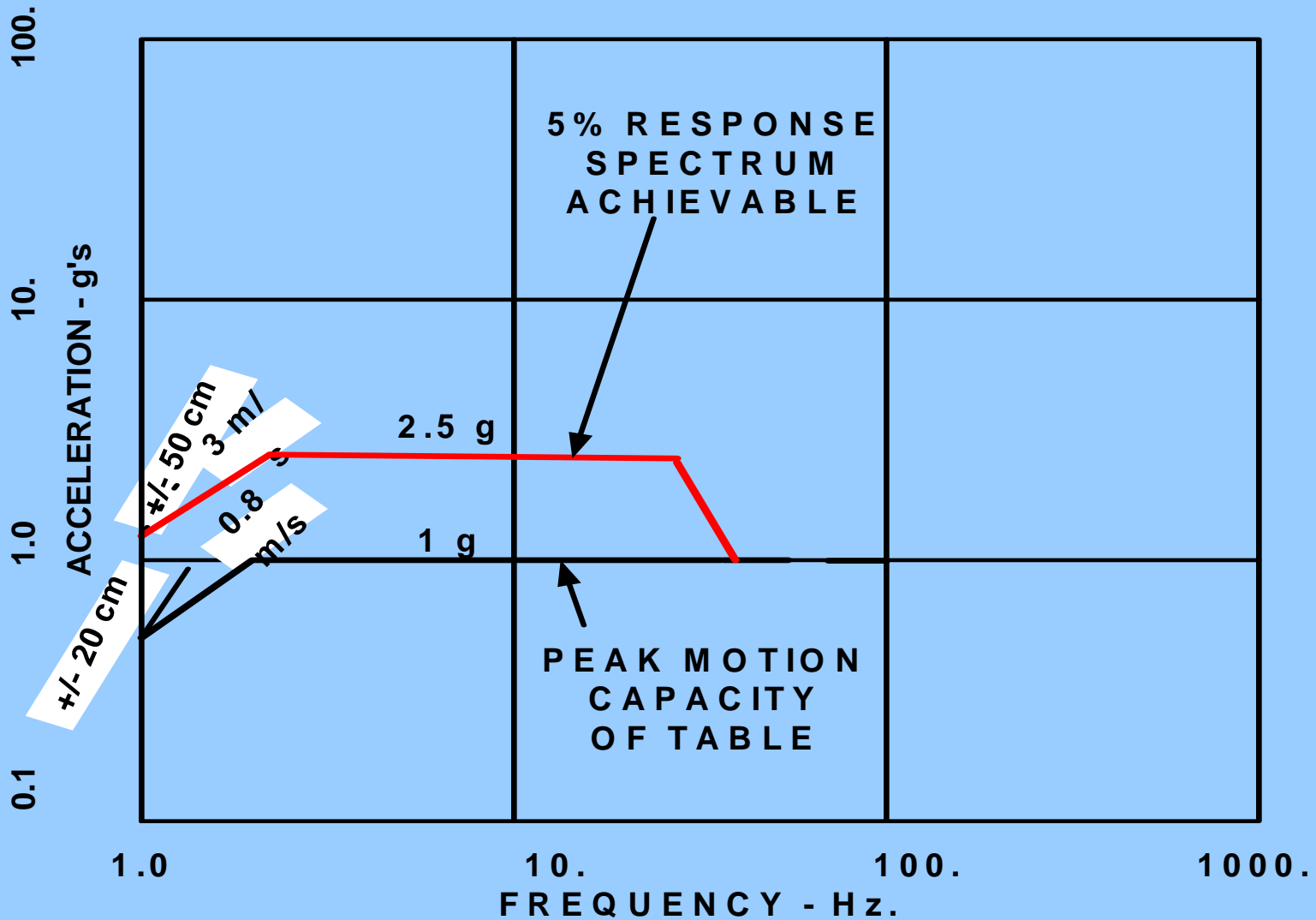
TABLE SPECIFICATIONS

- **1 AXIS HORIZONTAL SHAKE TABLE**
- **30 TON SERVO-HYDRAULIC ACTUATOR**
- **3 M X 3 M STEEL TABLE TOP**
- **10 TON MAXIMUM NOMINAL PAYLOAD**
- **1.3 G MAXIMUM ACCELERATION WITH 10 TON PAYLOAD**
- **~ 4.0 G BARE TABLE ACCELERATION**
- **0.8 M/S MAXIMUM VELOCITY**
- **+/- 200 mm MAXIMUM DYNAMIC DISPLACEMENT**

TABLE SPECIFICATIONS (CONTINUED)

- **FREQUENCY RANGE: 0-50 TO OVER 100 HZ**
- **ANALOG REAL TIME DISPLACEMENT CONTROLLER**
- **DIGITAL ITERATIVE ACCELERATION CONTROLLER**
- **SINE, RANDOM, IMPULSE, ARBITRARY WAVEFORM**
- **RELOCATABLE ON THE NTU STRONG FLOOR**

TABLE MOTION CAPACITY



Achievable motion and 5% Response Spectrum for R-149 Table with 10,000 kg Test Specimen Mass

R-149 LAYOUT

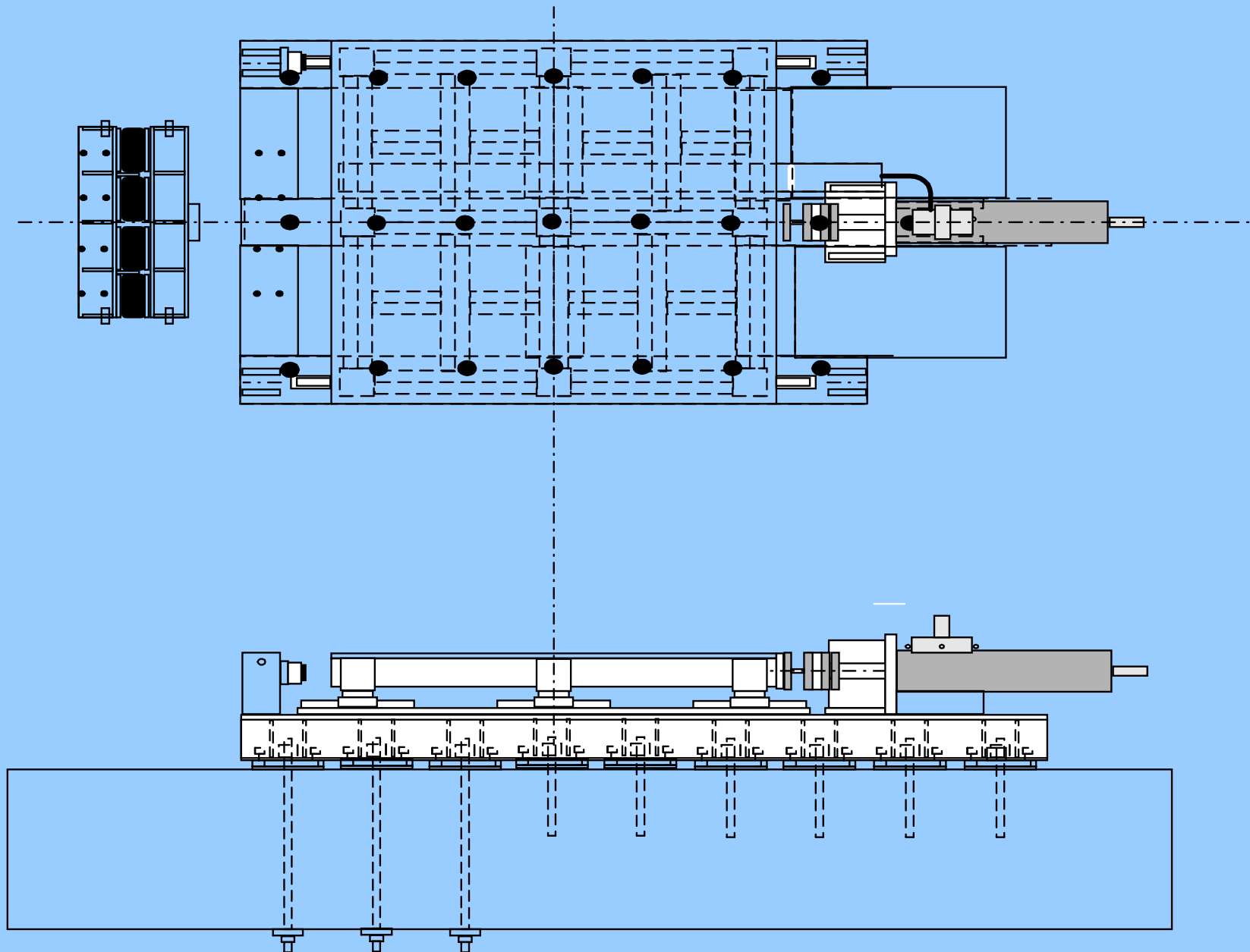
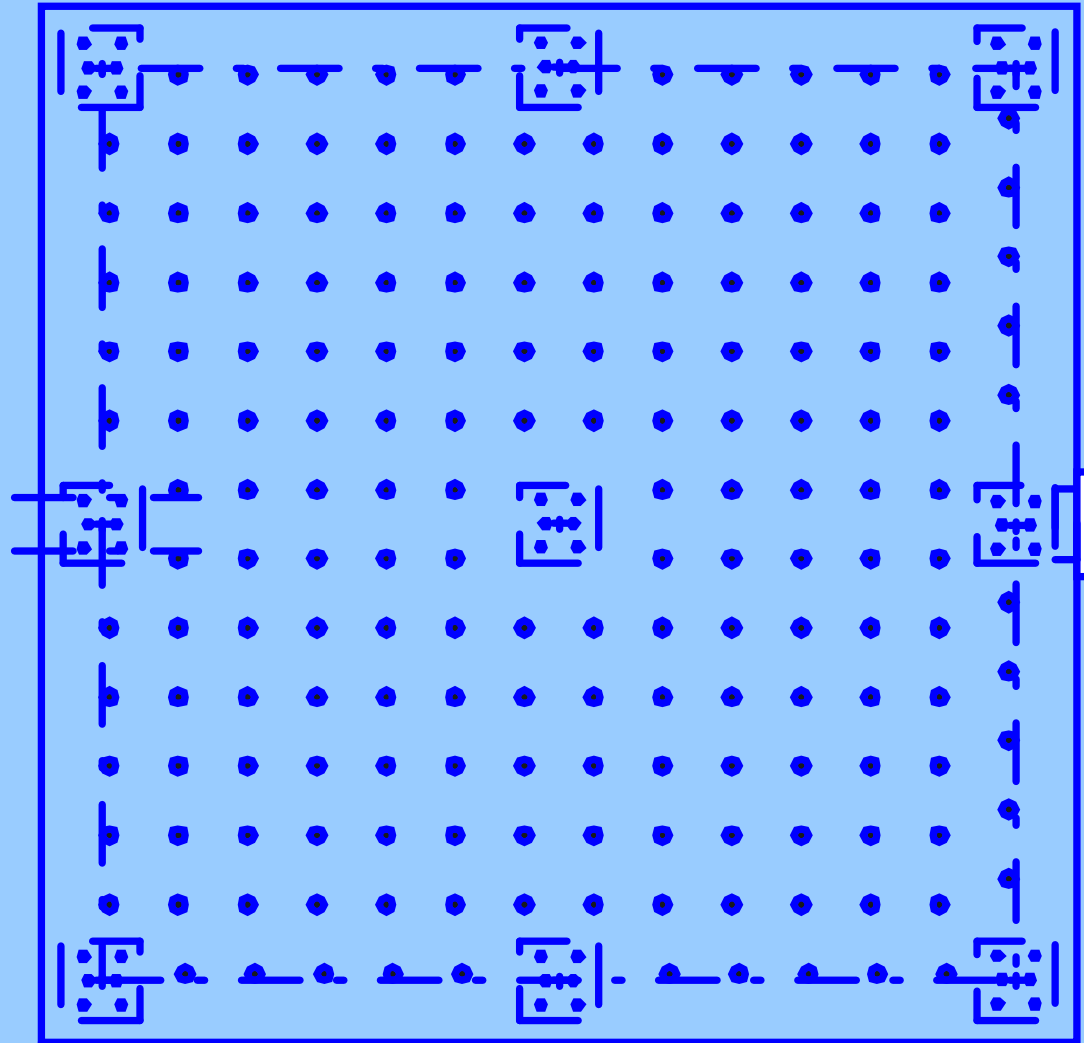


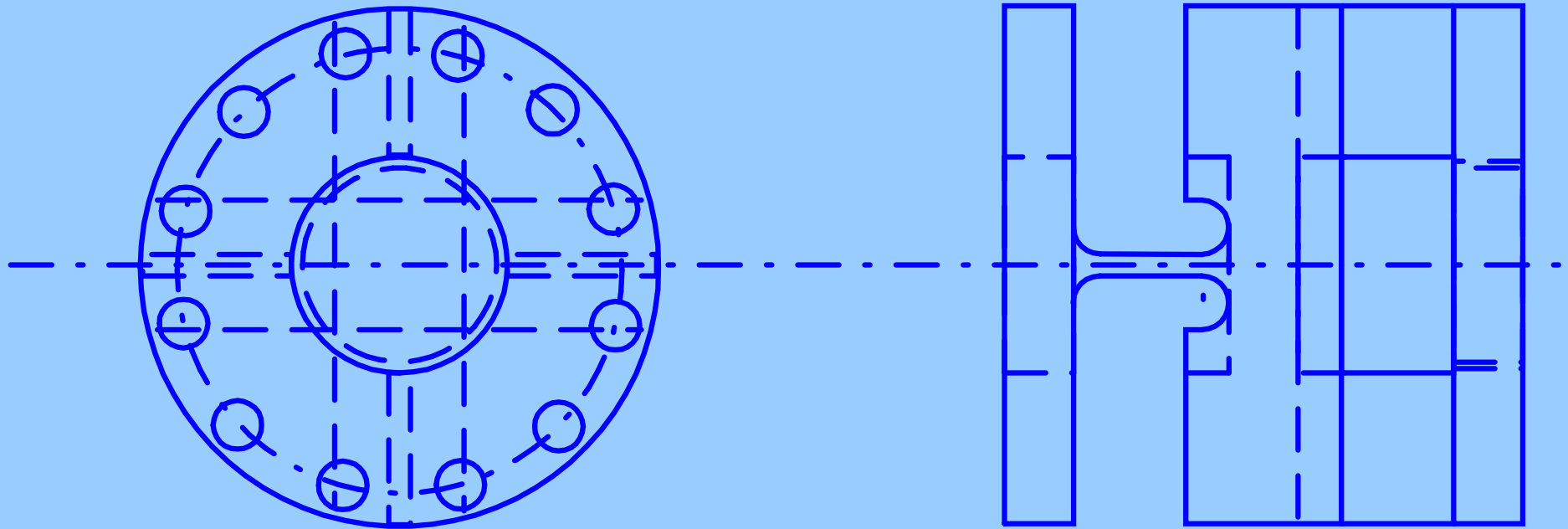
TABLE TOP GRID

M20X2.5 THREAD ON 200 mm SPACING, >30 mm DEEP

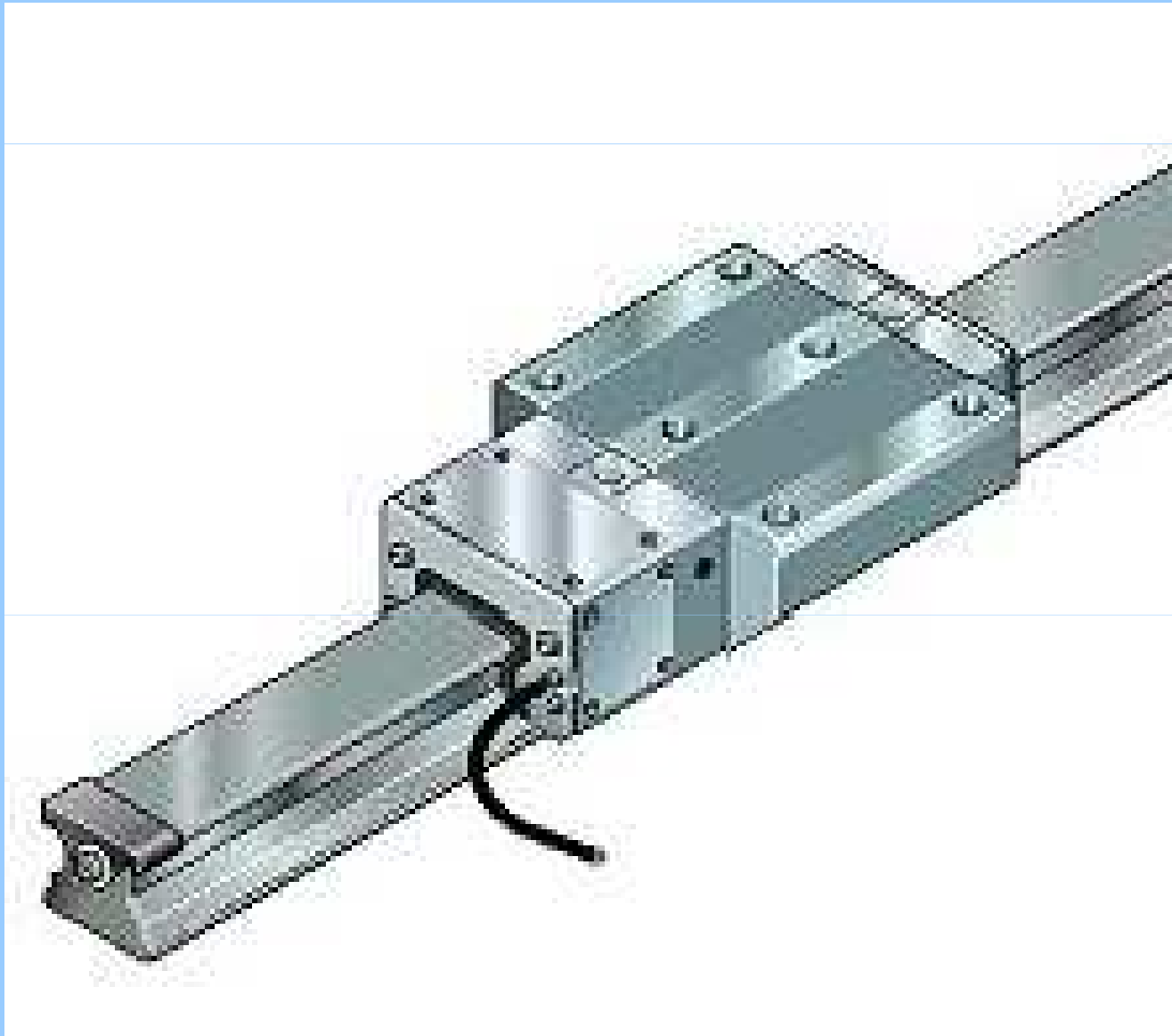


FLEX

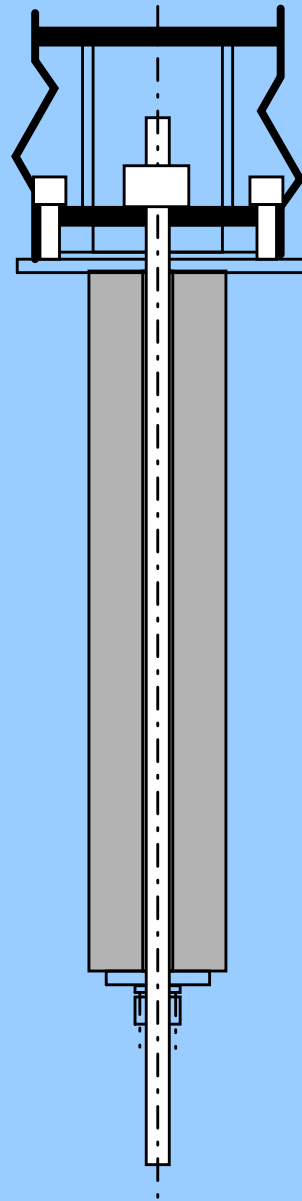
**NO GAP AXIALLY STIFF, ALLOWS TRANSVERSE AND
ROTATIONAL MISALIGNMENT**



LINEAR ROLLER BEARINGS (9 SETS)

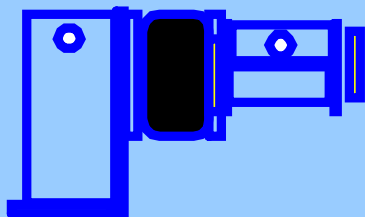
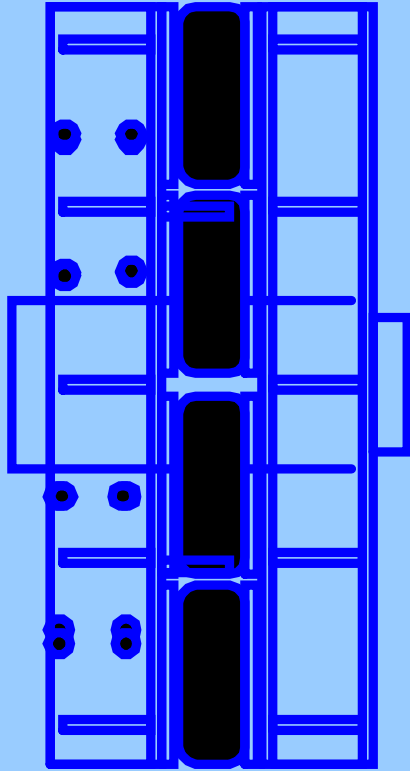


ANCHORAGE (23 UNITS)

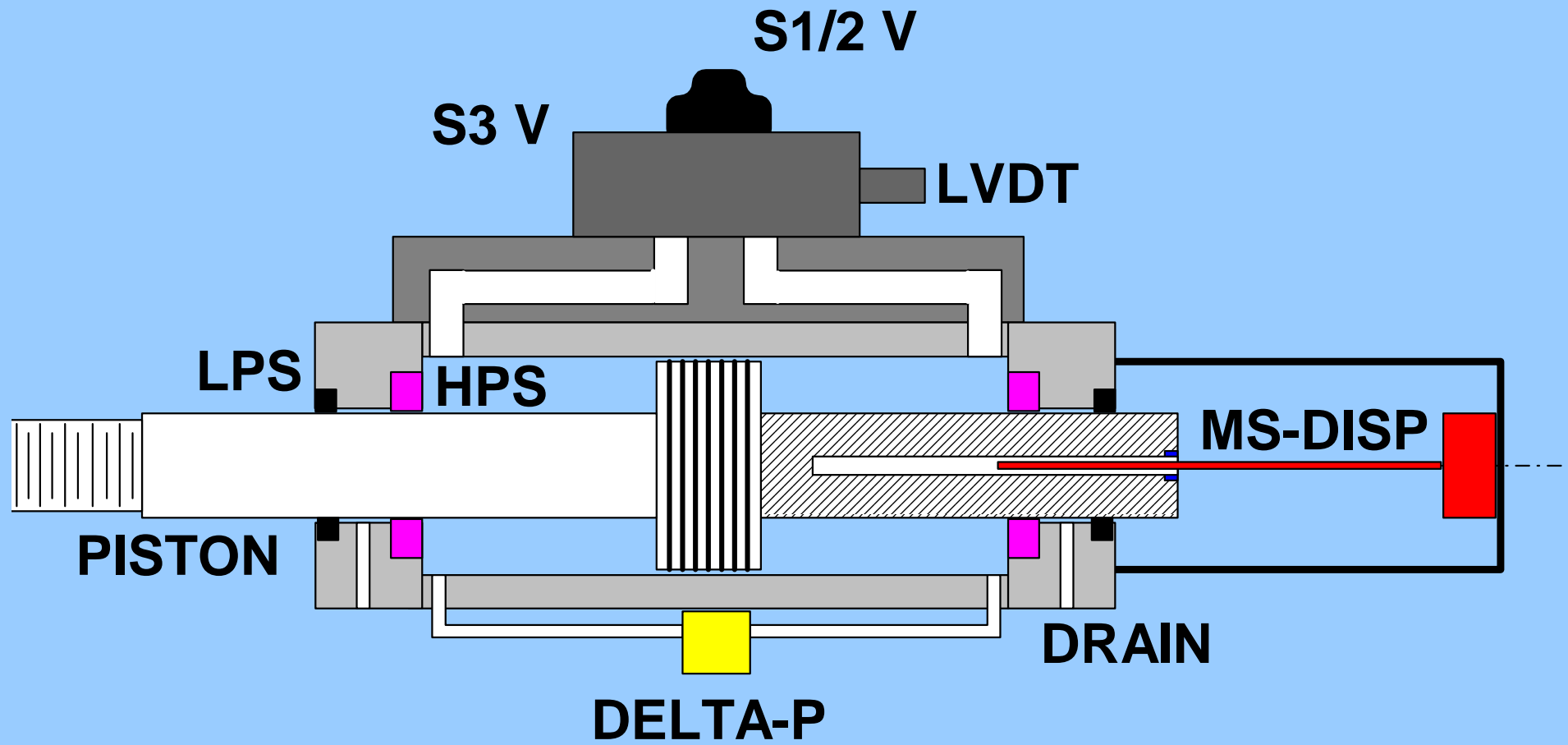


AIRBAG ASSEMBLY

FOR STIFF IMPULSE BIAS



ACTUATOR



200 GPM (757 L/MIN) 3 STAGE 7600 SERVO VALVE



SERVO CONTROLLER

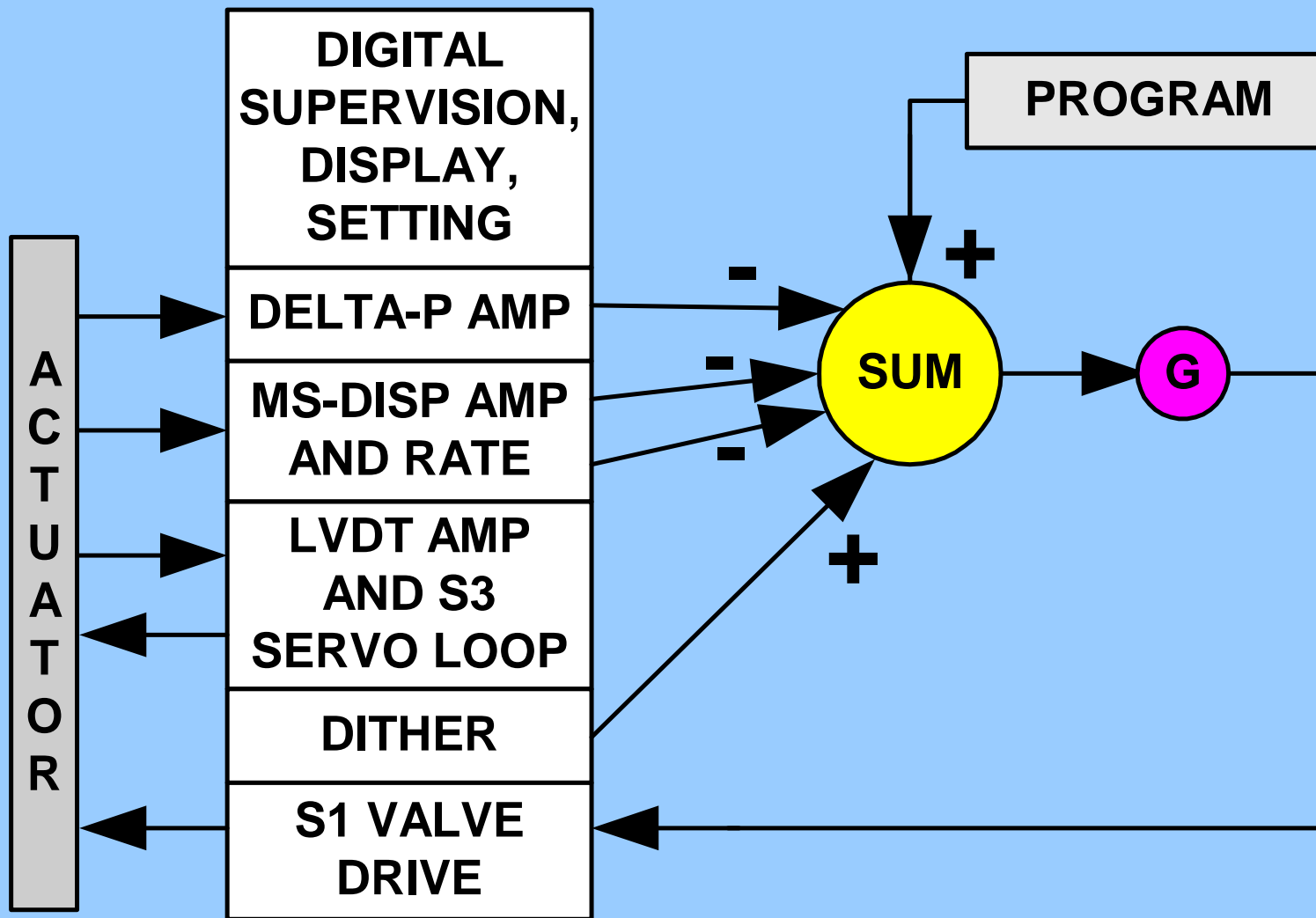


TABLE HYDRAULIC MANIFOLD

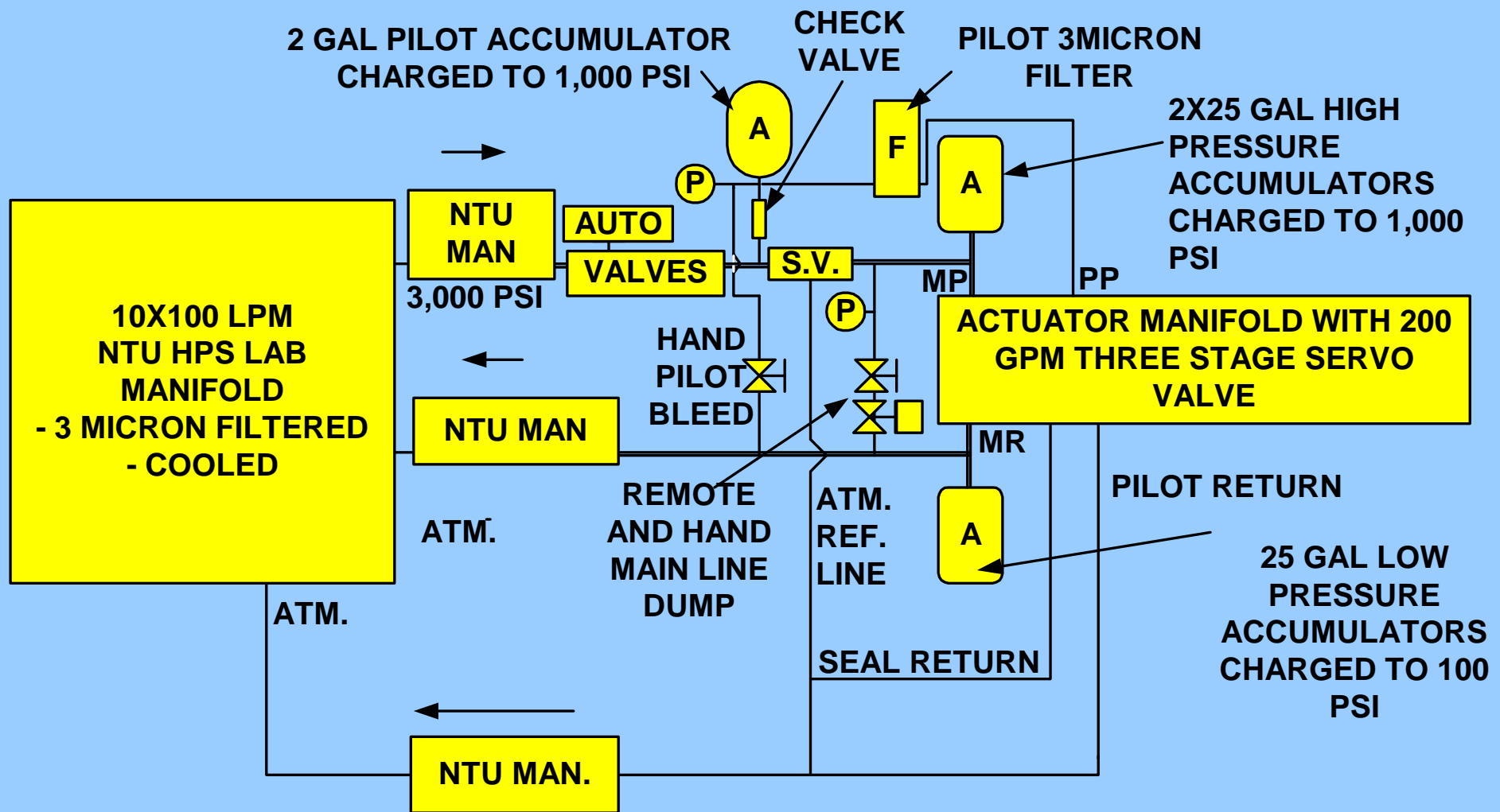
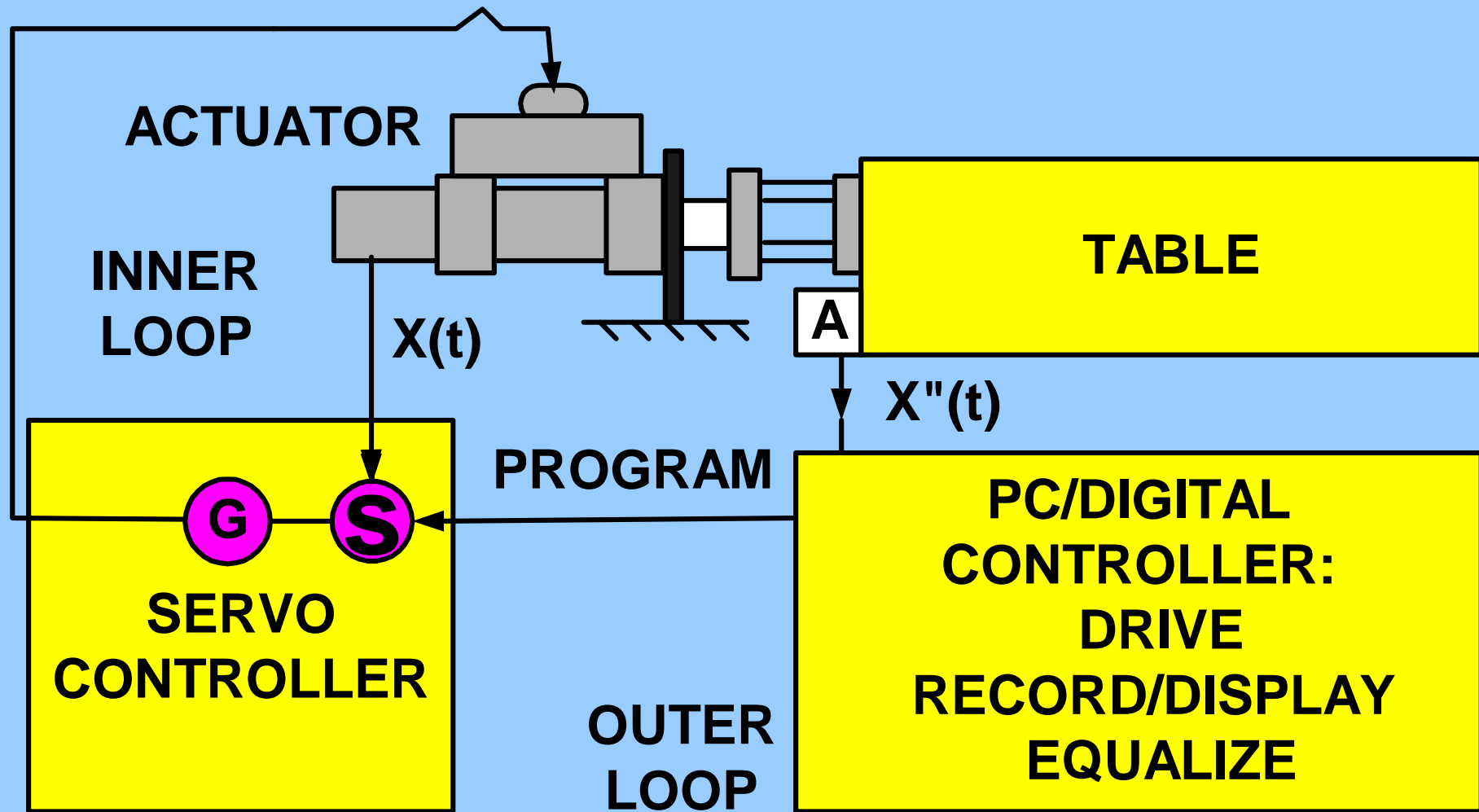


TABLE DUAL LOOP CONTROL SYSTEM



DIGITAL CONTROL AND DATA ACQUISITION

- **DATA PHYSICS VECTOR 550WIN SIGNAL-CALC WITH FFT PROCESSORS**
- **DELL PC, MONITOR, COLOR LASER PRINTER**
- **15 CHANNELS ADC**
- **1 CHANNEL DAC**
- **16 BIT, ANTI-ALIASING FILTERS, ICP**
- **GUI**

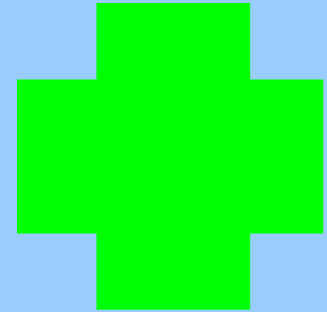
DP SIGNAL STAR VECTOR WITH GUI



DIGITAL CONTROL AND DATA ACQUISITION (CONTINUED)

- **GRAPHICAL DISPLAY AND EXPORT**
- **TEST DEFINITION, CALIBRATION,
DOCUMENTATION**
- **“PROGRAM” SIGNAL CREATION**
- **SPECTRUM COMPATIBLE EARTHQUAKE**
- **SYSTEM SAFETY MONITORING**
- **ITERATION EQUALIZATION**
- **3 DYTRAN ACCELEROMETERS**

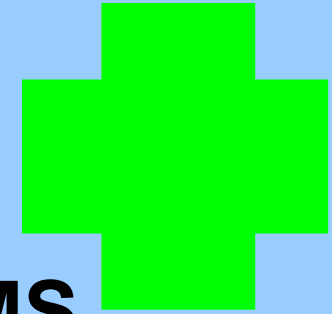
SAFETY ISSUES



- **HARD, FAST, POWERFUL**
- **PINCH POINTS**
- **EXCLUSION AREA**
- **HIGH OIL AND NITROGEN PRESSURE/FLOW**
- **HIGH ELECTRICAL VOLTAGE/POWER**
- **HEAVY WEIGHTS/CRANE**

ENGAGE BRAIN BEFORE TABLE !

SAFETY ISSUES (CONTINUED)

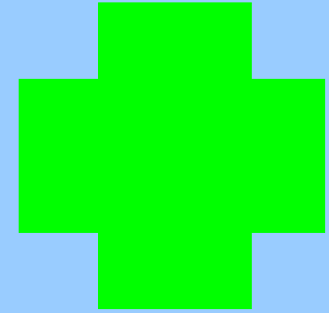


- **POTENTIALLY DAMAGED TEST ITEMS**
- **POTENTIAL TO OVERDRIVE**
- **SENSITIVE TO POWER OFF OR LOSS**
- **AUTOMATIC OPERATION**
- **INTERACTION WITH OTHER LAB SYSTEMS**
- **POTENTIAL EQUIPMENT DAMAGE**
- **REQUIRES TRAINED OPERATORS**
- **REQUIRES UPS**

RAUMOKO IS AN ANGRY GOD !

SAFETY ISSUES

- DESIGNED SAFETY FEATURES -



- ELECTRONIC DISPLACEMENT LIMITS
- PC LIMITS ON MAX X , X' , X''
- PC LIMITS ON MAX DRIVE VOLTAGE
- AUTOMATIC DUMP AND ZERO PROGRAM ON SHUTDOWN OR E-STOP
- UPS
- SOFT/HARD STOPS
- FLASHING LIGHT ON ACTUATION

DO NOT BYPASS THESE FEATURES !

MAINTENANCE



- **VALVE CLEANING**
- **ACCUMULATOR CHARGING/CHECKS**
- **BEARINGS GREASING/CHECKS**
- **FILTERS AND OIL CLEANLINESS**
- **ACTUATOR CARE/CHECKS**
- **ACTUATOR ALIGNMENT**

MAINTENANCE (CONTINUED)



- **BOLT AND CABLE TIGHTNESS**
- **ANCHORAGE INSPECTION**
- **FLEX AND TABLE TOP CARE**
- **ELECTRICAL CABLE CHECKS**
- **SPARE PARTS AND CONSUMABLES**
- **TABLE RELOCATION**
- **ELECTRONICS AS NEEDED**

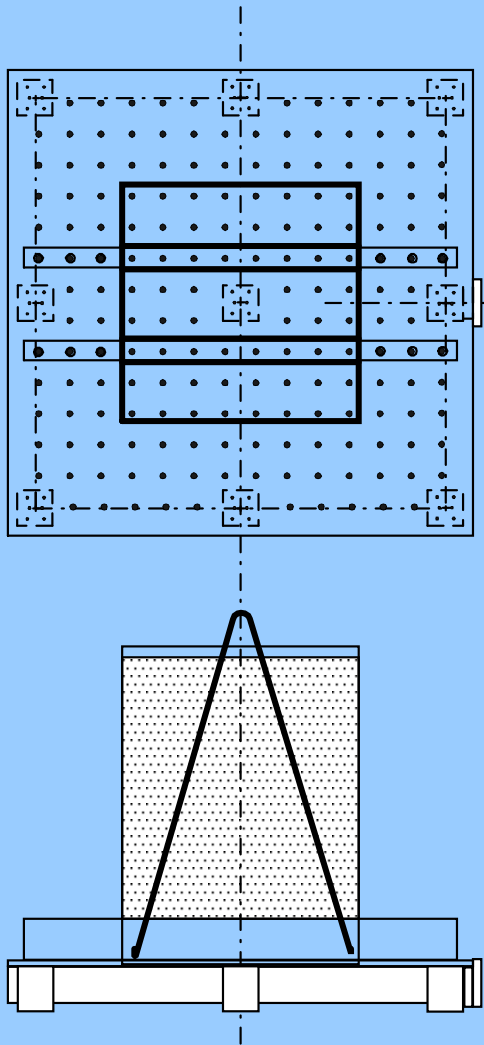
TYPICAL TESTING PROCEDURES

- **INDUSTRIAL AND GOVERNMENT STANDARDS (IEEE-344, TELCORDIA GR-63, QME-100, MIL-STD 810, MIL STD 167, ETC.)**
- **DESIGN OF TEST OBJECT AND TEST PLAN**
- **CONSTRUCTION OF TEST OBJECT AND ATTACHMENT TO TABLE, INSTRUMENTATION**

TYPICAL TESTING PROCEDURES (CONTINUED)

- **INSTRUMENTATION AND PC SET UP, TABLE CHECKOUT (POSSIBLY WITH DUMMY MASS)**
- **SAFETY REVIEW**
- **PRELIMINARY TESTING AND DATA ANALYSIS**
- **FULL SCALE TESTS**
- **DATA ANALYSIS AND RETESTING, AS NEEDED**
- **TEARDOWN AND TABLE MAINTENANCE/CLEANUP**

10 TON TEST MASS AND SITE ACCEPTANCE TEST (SAT)



COMMISSIONING:

SAT WILL DEMONSTRATE

- ***SYSTEM COMPONENT T
OPERATION***

- ***MAX PERFORMANCE***

- ***SOFTWARE
PERFORMANCE***

DOCUMENTATION



- R-149 USER'S MANUAL
- THIS POWER POINT PRESENTATION
- GS SERVO CONTROLLER MANUAL
- DP MANUAL (CD)
- DELL PC MANUAL/WINDOWS OP SYS.
- MINOLTA PRINTER MANUAL
- WAVETEK MANUAL
- DYTRAN ACCELEROMETER/AMP MANUAL

SUPPORT ORGANIZATIONS

- **ANCO Engineers**
(COLORADO)

- **CENTIFORCE**
(SINGAPORE)

- **DATA PHYSICS**
(SINGAPORE/CALIFORNIA)

- **GARDNER SYSTEMS**
(CALIFORNIA)

- **MOOG VALVES**
(SINGAPORE/NEW YORK)

- **DELL**
(SINGAPORE)

- **E-MAIL**
- **WEB SITE**
- **TELEPHONE**
- **FAX**
- **IN PERSON**

ANCO Engineers, Inc.

We talk shake tables.

We look forward to being of assistance.

- **Systems**
- **Installation**
- **Training**
- **Maintenance**
- **Service**

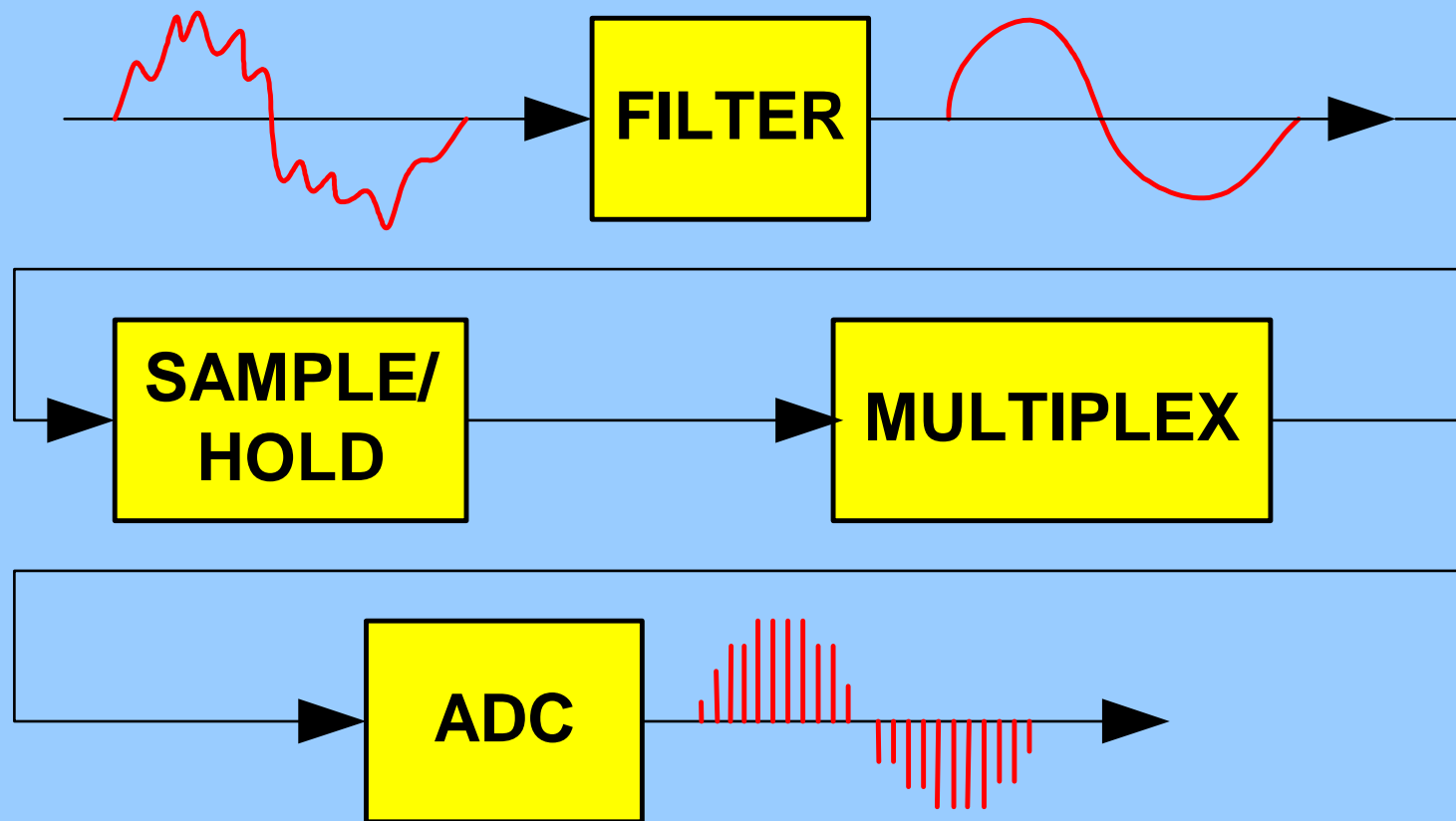


Module 2

DIGITAL DATA ACQUISITION, ANALYSIS, AND CONTROL

ADC

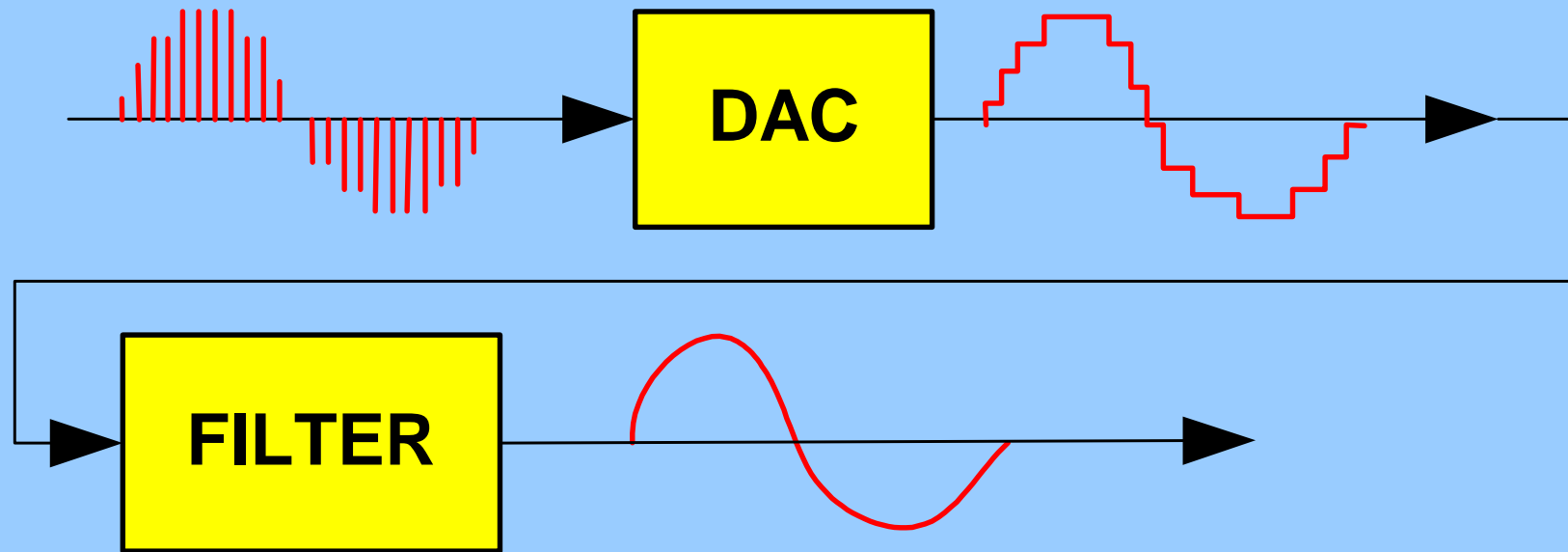
ANALOG TO DIGITAL CONVERTER



**SAMPLING RATE (S/SEC), QUANTIZATION (BITS),
DYNAMIC RANGE, SLEW**

DAC

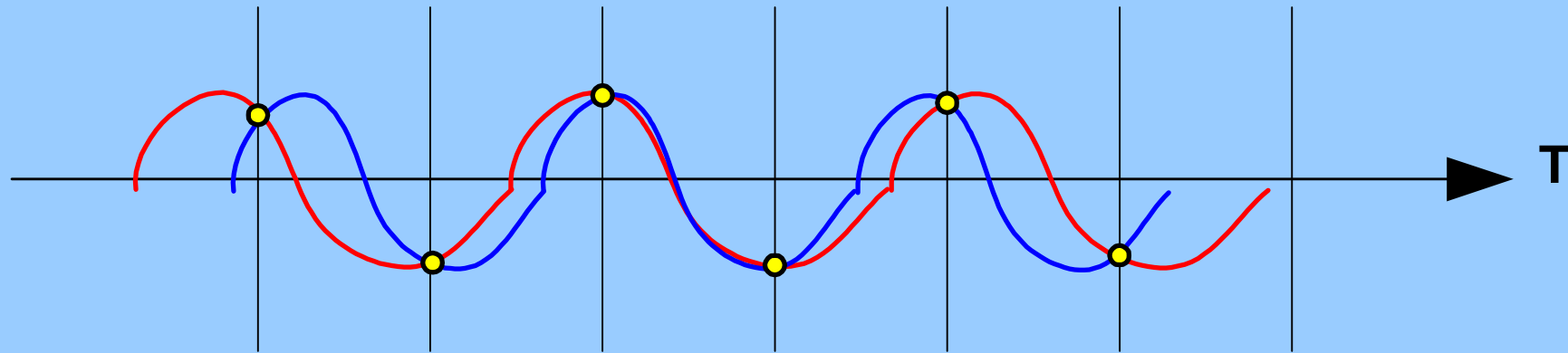
DIGITAL TO ANALOG CONVERTER



**SAMPLING RATE (S/SEC), QUANTIZATION (BITS),
DYNAMIC RANGE, SLEW**

ALIASING

ALIAS: AN ALTERNATE NAME OR IDENTITY



WHEN SAMPLED AT 2.0 CYCLE/SEC A 1.1 AND 0.9
HZ SINE WAVE YIELDS IDENTICAL DATA

NYQUIST FREQUENCY (1/2 SAMPLING RATE)
SHANNON SAMPLING THEOREM (A MINIMUM)

FILTERS

- FILTERS ARE USED FOR ANTI-ALIASING AND DATA CLARIFICATION
- USE FILTERS CAREFULLY DUE TO AMPLITUDE, PHASE, AND ENERGY CONTENT DISTORTION
- FILTER TYPE: BUTTERWORTH, BESSEL, ELLIPTICAL, CHEBYSHEV, GAUSSIAN ETC.
- LOW PASS, HIGH PASS, BAND PASS, NOTCH FILTERS

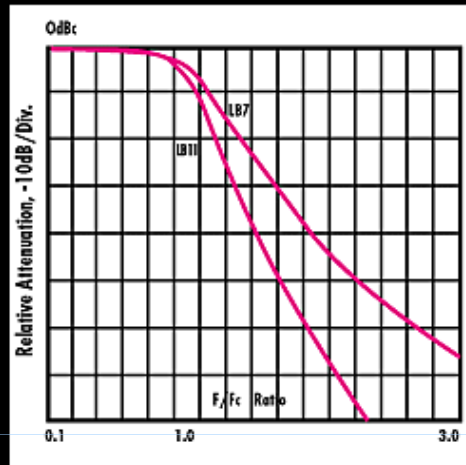


FILTER TERMINOLOGY

CUT OFF, ROLL OFF, PHASE, DELAY

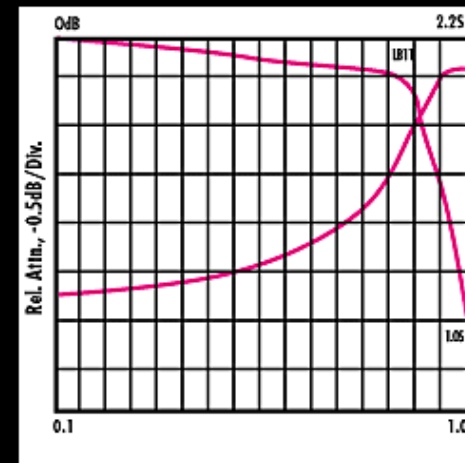
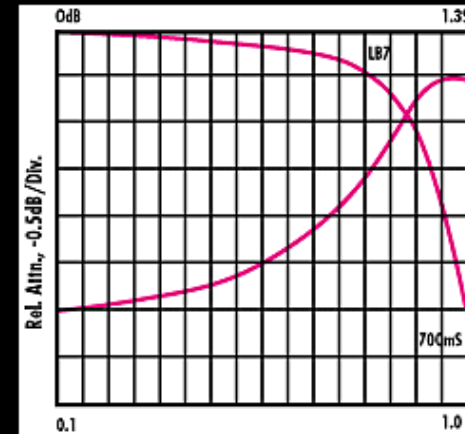
Normalized at 1Hz:

Overall Response.



Normalized at 1Hz:

Passband and Time Delay.



FOURIER TRANSFORM, DFT

$$F(\omega) = \int_{-\infty}^{+\infty} X(t) e^{i\omega t} dt$$

$$DFT(\omega) = \sum_{j=1}^N X(t_j) e^{i\omega_j \Delta t}$$

N^2 OPERATIONS

INVERSE TRANSFORM

- **THE INVERSE FOURIER TRANSFORM EXISTS AND ALLOW CONVERSION OF A FREQUENCY DOMAIN FUNCTION INTO THE TIME DOMAIN.**
- **HENCE FREQUENCY DOMAIN MANIPULATIONS CAN BE USED TO EFFECT THE TIME DOMAIN (E.G. FILTERING, INTEGRATION, TRANSFER FUNCTIONS)**

FFT

- **COOLEY AND TUKEY DISCOVERED A CLOSELY RELATED TRANSFORM CALLED THE Z-TRANSFORM THAT IS SIMILAR TO THE FOURIER TRANSFORM BUT OPERATES ON DIGITIZED TRACES**
- **THEIR ALGORITHM EVALUATES THE FOURIER TRANSFORM IN $N \cdot \log(N)$ STEPS AND HENCE IS CALLED THE FAST FOURIER TRANSFORM (FFT)**

TRANSFER FUNCTION

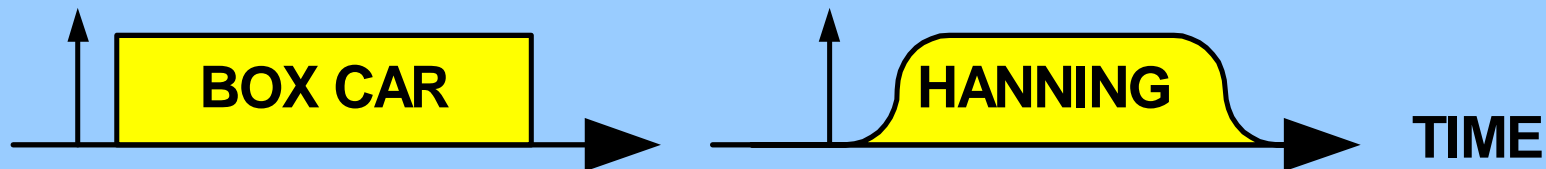
- A LINEAR SYSTEM HAS A FREQUENCY DEPENDENT TRANSFER FUNCTION, H , RELATING ITS RESPONSE, Y , TO ITS INPUT, X :

- $$Y = H * X$$

- $$X = H^{-1} * Y$$

WINDOWS

- **THE Z-TRANSFORM AND FFT OPERATE ON A FINITE TIME SERIES WRAPPED ONTO ITSELF (FINAL TIME POINT FOLLOWED BY FIRST TIME POINT).**
- **TO AVOID A DISCONTINUITY AND THE INTRODUCTION OF FALSE ENERGY AT THIS MEETING OF FIRST AND LAST POINT THE TIME HISTORY IS TAPERED BY A WINDOW.**
- **DIFFERENT WINDOWS AFFECT AMPLITUDES AND PEAK WIDTHS IN DIFFERENT WAYS.**



RANDOM, PSD

A RANDOM TIME HISTORY HAS:

- SIMILARITY OVER TIME (STATIONARITY)
- DIFFERENT ENERGY AT DIFFERENT FREQUENCIES GIVEN BY THE POWER SPECTRAL DENSITY (PSD) WITH UNITS SUCH AS G-SQUARED/Hz



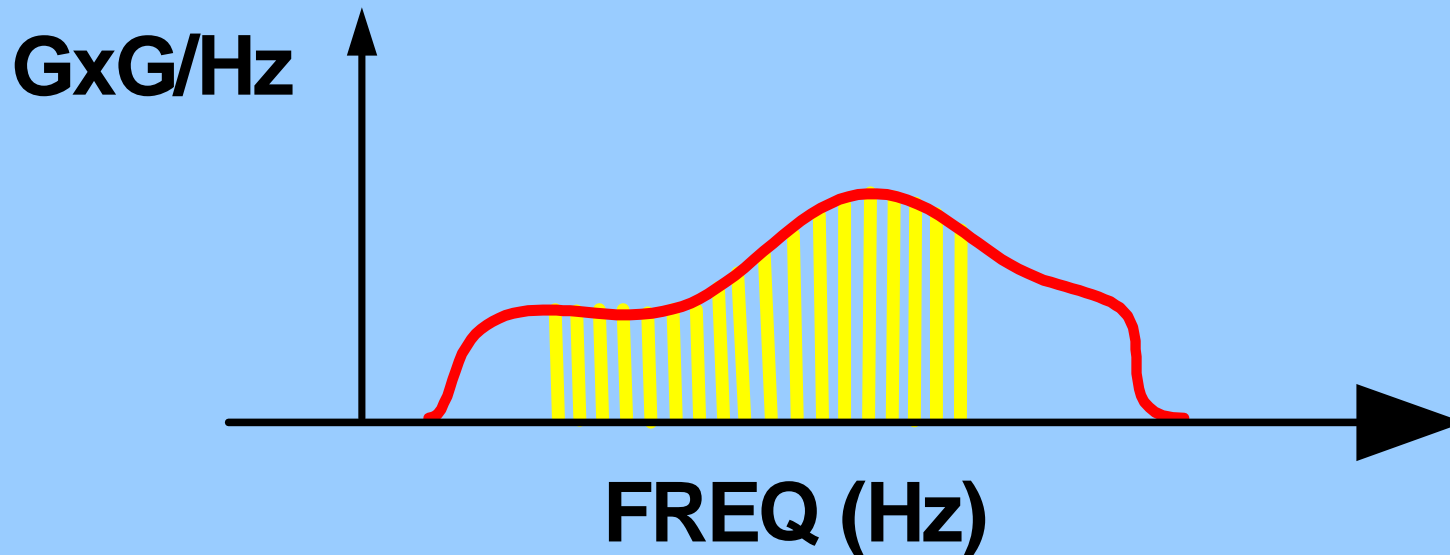
PSD COMPUTATION

THE PSD CAN BE ESTIMATED BY THE FOLLOWING STEPS:

- **BREAK THE TIME HISTORY INTO SEGMENTS**
- **MULTIPLY BY A WINDOW**
- **TAKE THE FFT AND SQUARE IT**
- **AVERAGE THE VARIOUS SQUARED FFT'S**

PSD AND RMS VALUE

THE SQUARE ROOT OF THE AREA UNDER THE PSD IS THE RMS VALUE OF THE TIME HISTORY IN THE FREQUENCY BAND CHOSEN



CREST FACTOR, HASH, OCTAVES, AND DECIBELS

- THE CREST (SIGMA) FACTOR LIMITS THE MAX ACCELERATION ABOVE THE RMS – TYPICALLY 3-4 TIMES
- HASH OCCURS ON A PSD DUE TO NOISE, NONLINEARITIES AND NUMERICAL ESTIMATION LIMITS
- OCTAVE = FACTOR OF 2 IN FREQUENCY
- $db = 20 \times \log_{10} \{ \text{AMPLITUDE RATIO} \}$

SINE DWELL, SINE SWEEP

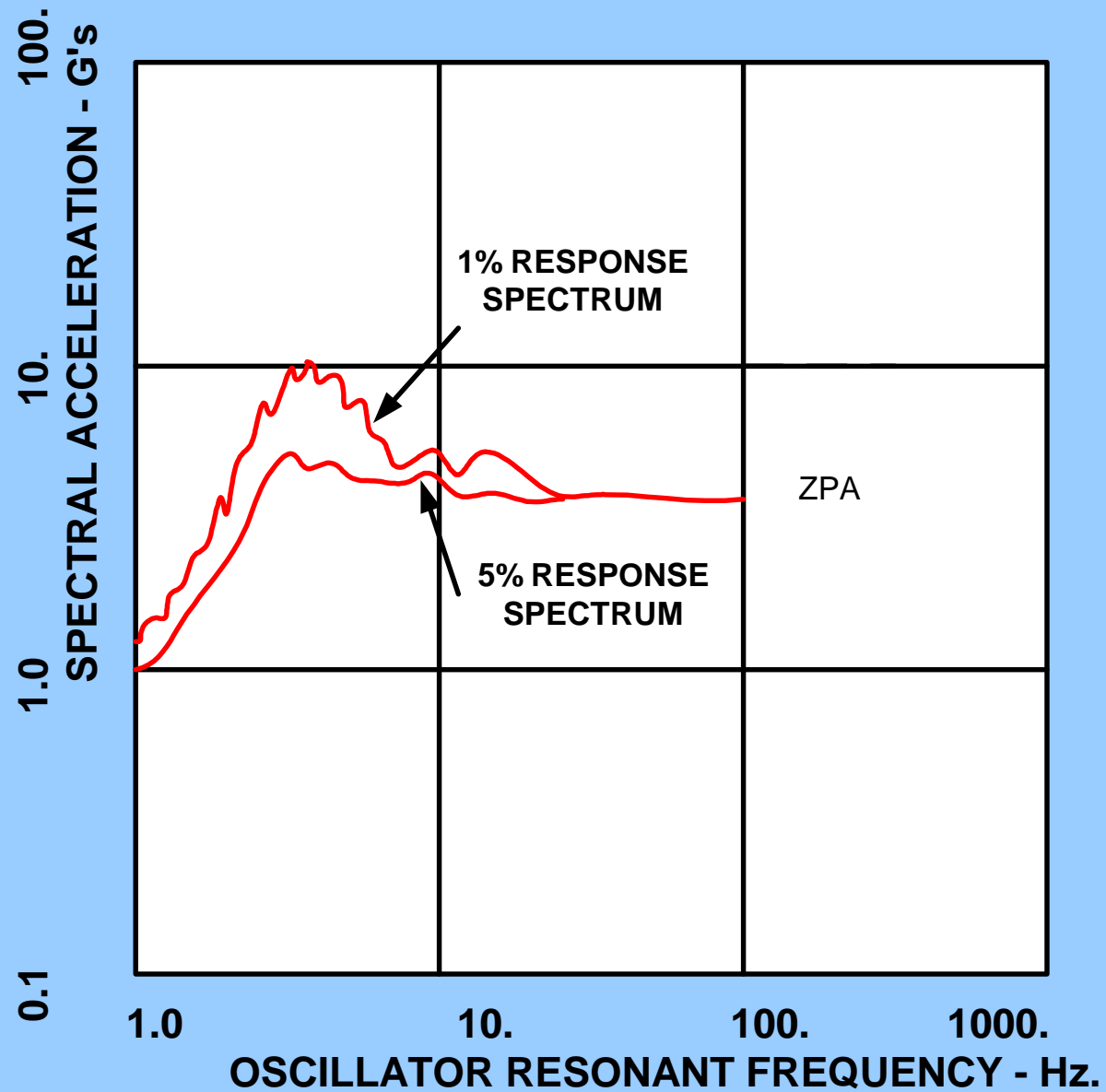
- **SINE DWELL: ONE OR MORE SINGLE FREQUENCY STEPS HELD FOR A GIVEN PERIOD OF TIME**
- **SINE SWEEP: A SINE WAVE OF CONTINUOUSLY VARYING FREQUENCY – INCREASING OR DECREASING AT LINEAR (Hz/SEC) OR LOGARITHMIC (OCTAVES/SEC) RATE**
- **THE SINE AMPLITUDE IS DEFINED BY A FREQUENCY DEPENDENT SPECTRUM**

TRANSIENT, SEISMIC

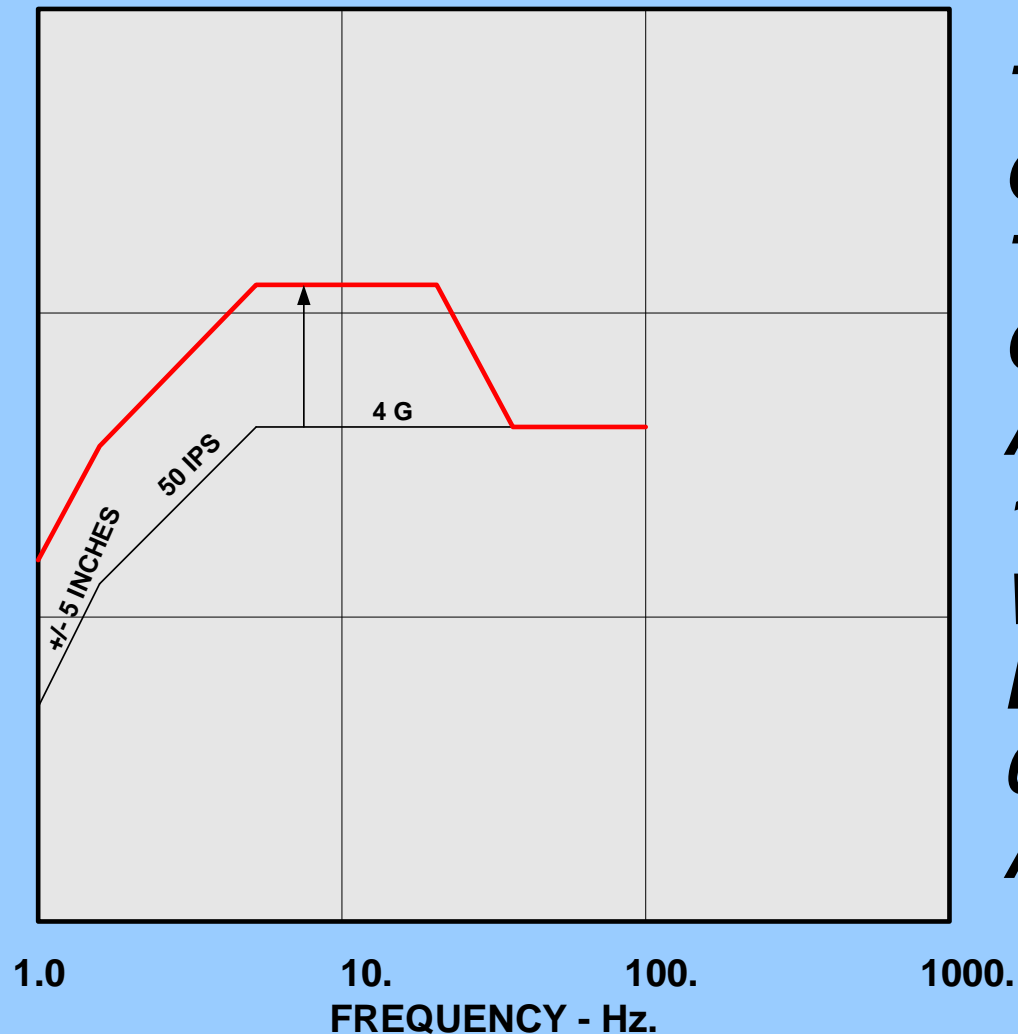
A TIME HISTORY OF FINITE DURATION,
TYPICALLY RANDOM IN NATURE BUT
CAN BE SINUSOIDAL, IMPULSIVE, ETC.
AS DESIRED BY THE USER



RESPONSE SPECTRUM



DEVELOPMENT OF TABLE AND SITE RESPONSE SPECTRA



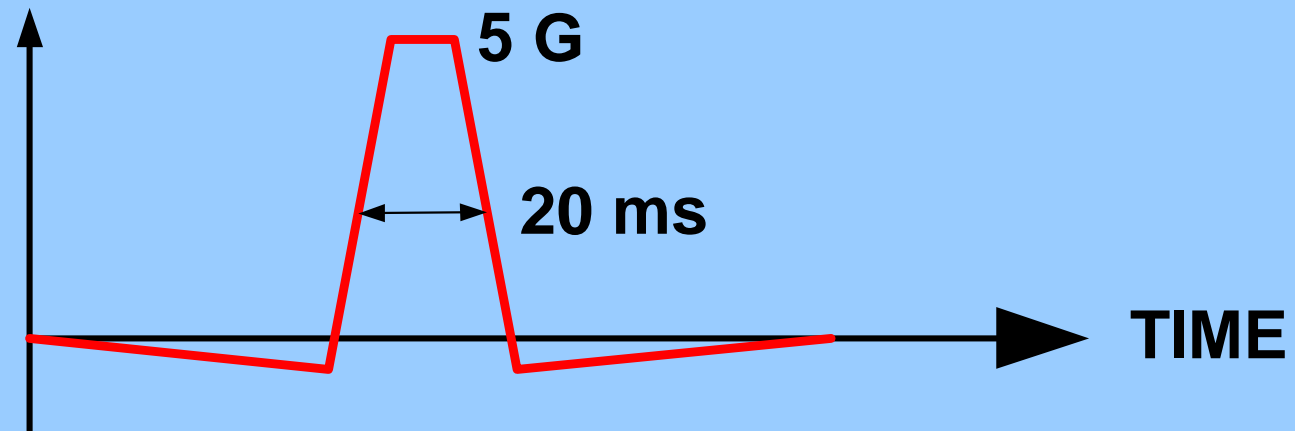
***THE AMPLIFICATION
OF THE RS ABOVE
TABLE CAPACITY IS
GIVEN
APPROXIMATELY BY
 $1/\text{SQRT}(2B)$
WHERE $B =$
DAMPING, FOR
 $0.01 < B < 0.10$
AND $1.0 < f < 30.0$***

RRS AND TRS

- **RRS – REQUIRED RESPONSE SPECTRA, OFTEN AN IDEALIZED COMBINED AND BROADENED ENVELOPE OF MANY ACTUAL SPECTRA. THIS IS THE DESIRED SPECTRA FOR THE TEST**
- **TRS – ACTUAL ACHIEVED SPECTRA, WITH REALISTIC HASH, HIGHER ZPA, WHICH EXCEEDS THE RRS IN A SPECIFIED FREQUENCY BAND**

IMPULSIVE AND SHOCK

- MOST OFTEN DEFINED BY INDUSTRIAL OR MILITARY STANDARDS. TYPICALLY SIMPLE IN SHAPE AND OF SHORT DURATION
- HALF SINE, TRIANGLE, TRAPEZOID, ETC.



Module 3

SERVO HYDRAULIC PUMP, MANIFOLD, ACTUATOR AND SERVO CONTROLLER

PUMP OPERATION AND SPECIFICATIONS

- MTS MULTIPLE UNIT PUMP RATED AT 10X100 LPM AT 3,000 PSI (207 BAR)
- MULTIPLE HYDRAULIC UNITS SERVICED
- MANIFOLDS REACH TO NEAR R-149 AND PROVIDE A 3 BALL VALVE SHUTOFF
- TURNED ON IN DISTANT PUMP ROOM
- **WARNING:** NTU SHOULD STRONGLY CONSIDER INSTALLING HIGH BAY FLASHING LIGHTS TO INDICATE PUMP ON, PLUS SEVERAL E-STOP BUTTONS

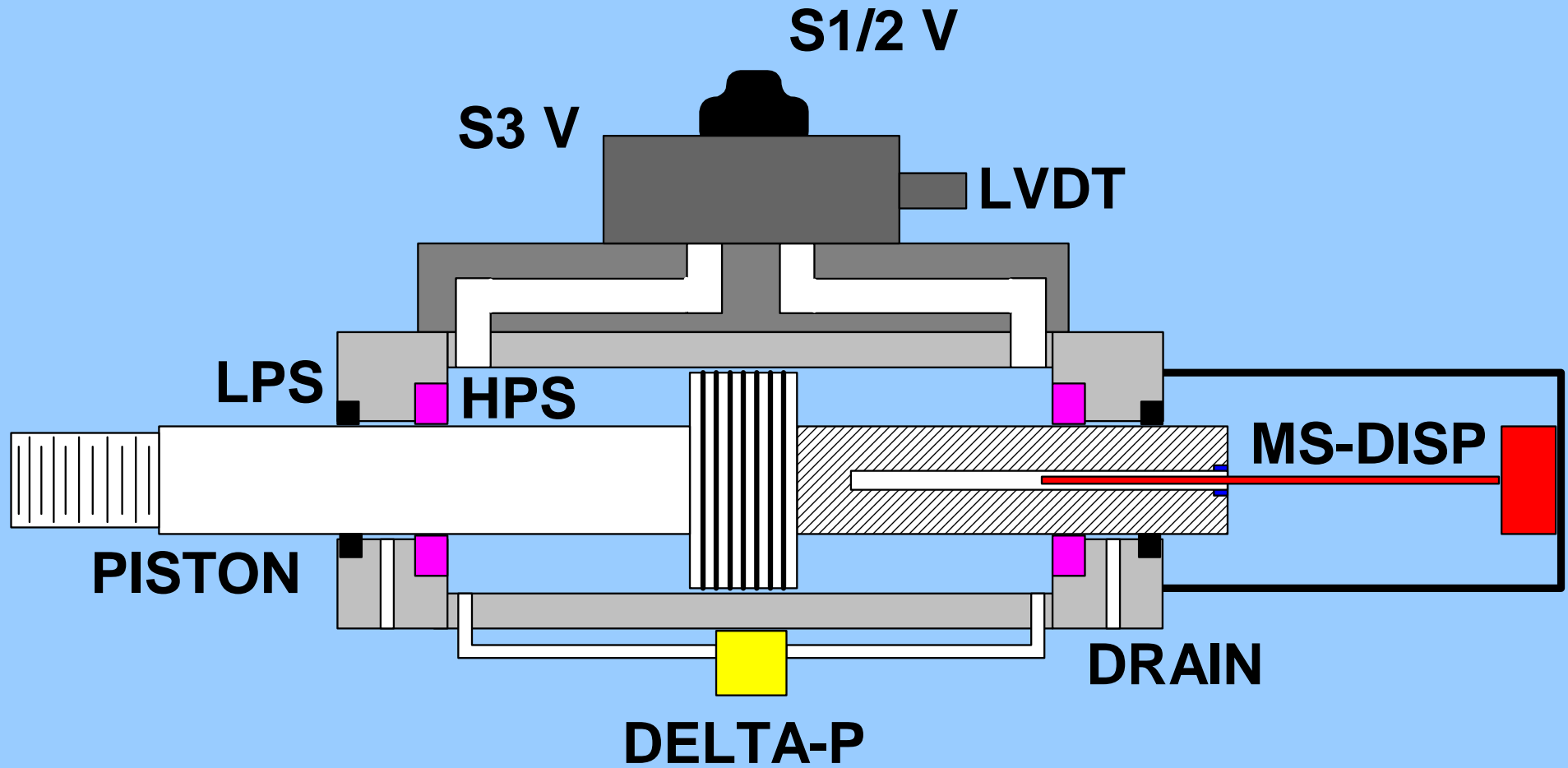
HYDRAULIC OIL PROPERTIES AND CLEANLINESS

- NOT BIOLOGICALLY HAZARDOUS
- FLASH POINT ABOUT 450 F (230 C)
- SLIP HAZARD, HIGH TEMPERATURE AND PRESSURE
- CAN BE DAMAGED BY EXCESSIVE HEAT (ABOVE 160 F/70 C)
- OIL CONTAMINATION IS THE NUMBER ONE CAUSE OF VALVE FAILURE. SEEK 3 MICRON FILTERING. REPLACE WHEN INDICATED
- REPLENISH WITH GOOD QUALITY PUMP MANUFACTURER RECOMMENDED OIL

OIL DRIPS AND PANS

- **THE ACTUATOR AND HOSE CONNECTIONS WILL EXPERIENCE SOME SLOW LEAKAGE. A PERIODIC WIPE DOWN WITH A CLOTH SHOULD KEEP THIS UNDER CONTROL**
- **INVESTIGATE AND CORRECT ANY LEAKAGE IN EXCESS OF THIS IMMEDIATELY (E.G. LOOSE HOSE FITTING)**
- **THERE ARE DRIP PANS TO EITHER SIDE OF THE ACTUATOR TO HELP CONTAIN ANY LEAK**

ACTUATOR

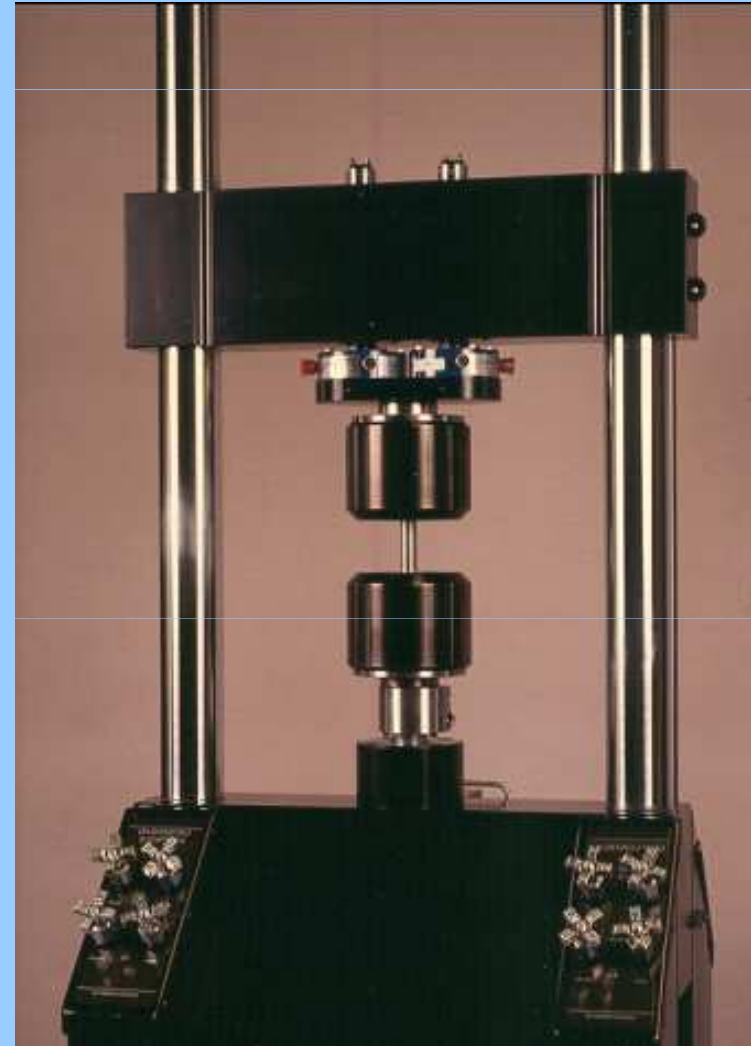


DISPLACEMENT SIGN CONVENTION

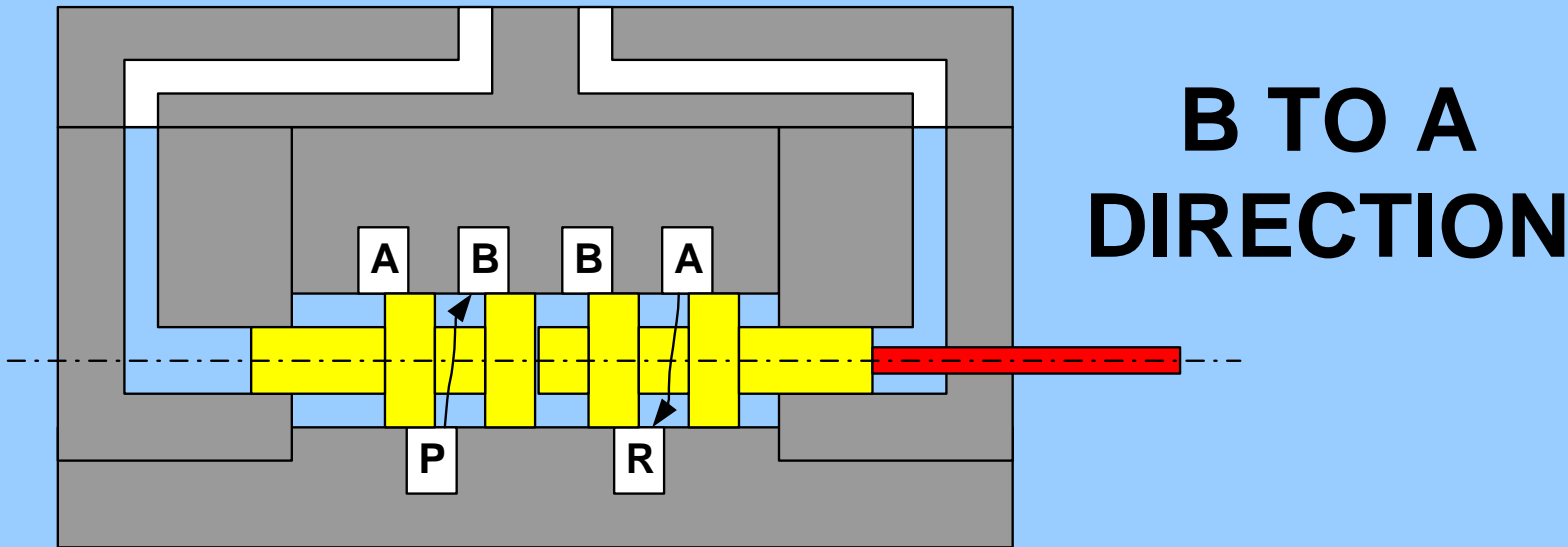
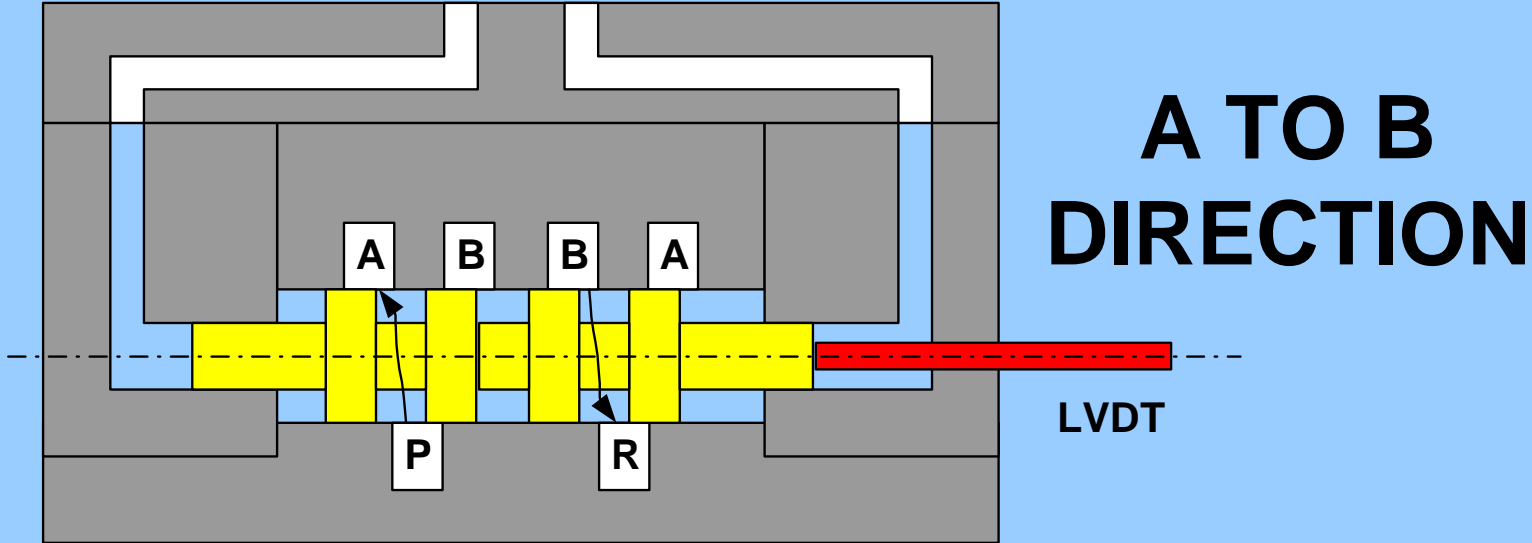
HIGH PERFORMANCE HYDRAULIC ACTUATORS WERE DEVELOPED FIRST FOR TENSILE TESTING MACHINES.

HENCE SHORTENING OF THE ACTUATOR, WHICH CAUSES SAMPLE TENSION, IS CONSIDERED POSITIVE.

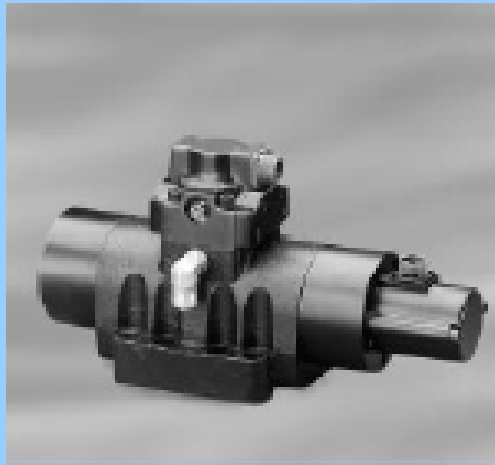
THIS IS CONFUSING FOR A SHAKE TABLE, BUT THE SAME CONVENTION HOLDS



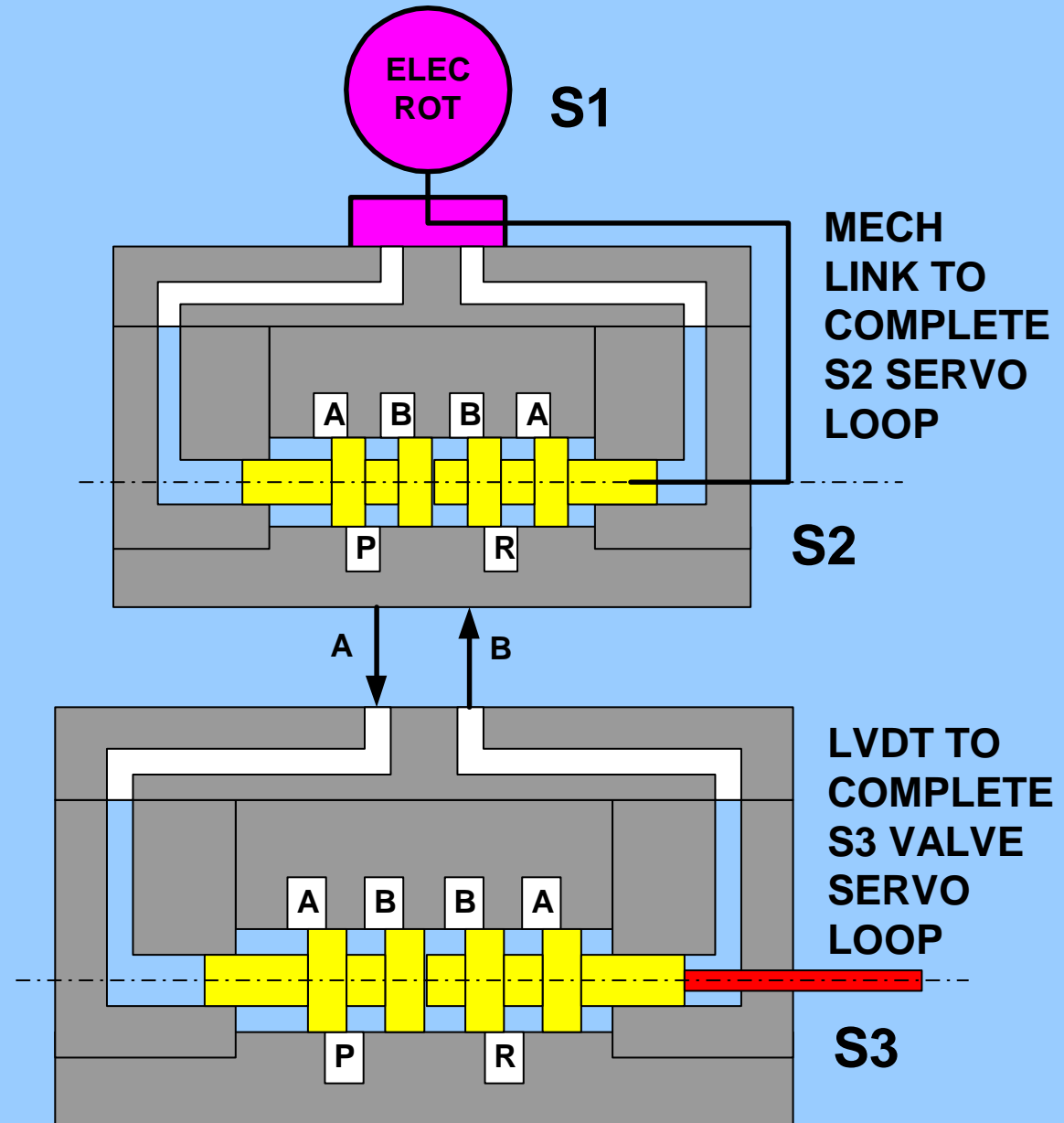
HYDRAULIC SERVO VALVE



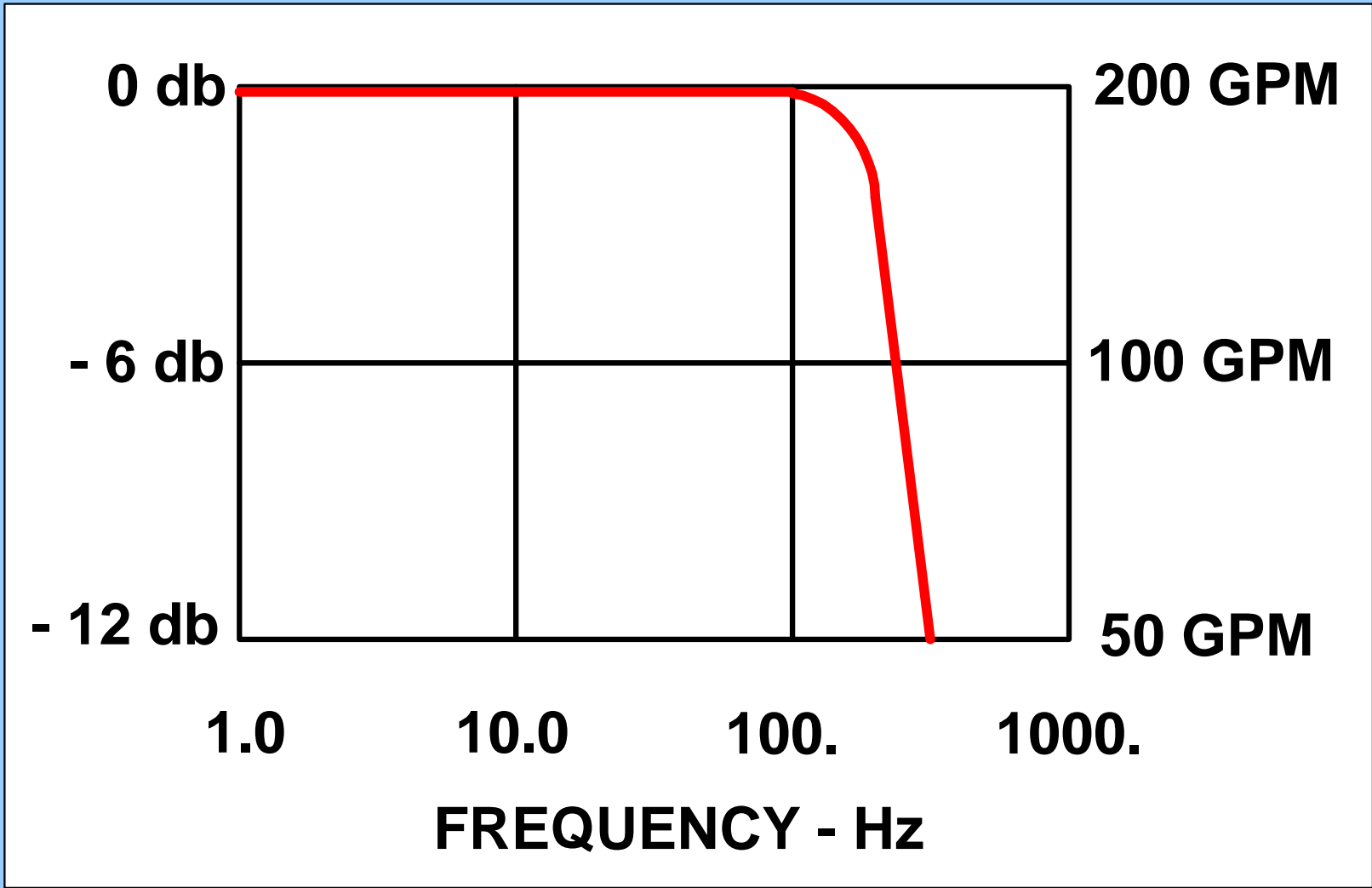
3 STAGE VALVE



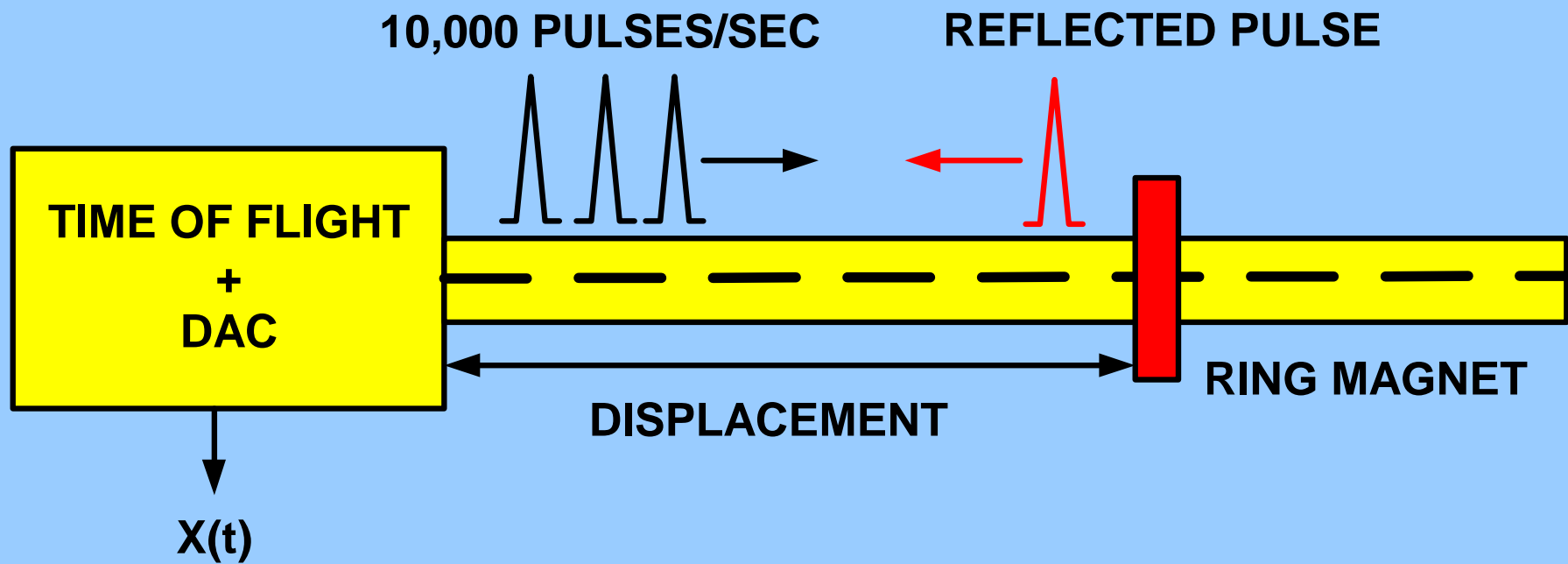
S1 + S2 = PILOT VALVE : 5 GPM
S3 = MAIN VALVE: 200 GPM



SERVO VALVE FREQUENCY RESPONSE



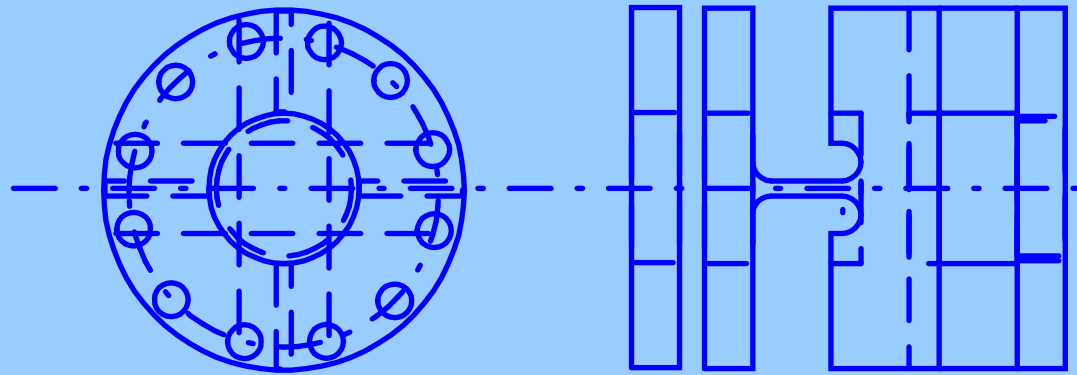
MAGNETOSTRICTIVE DISPLACEMENT SENSOR (BALUFF)



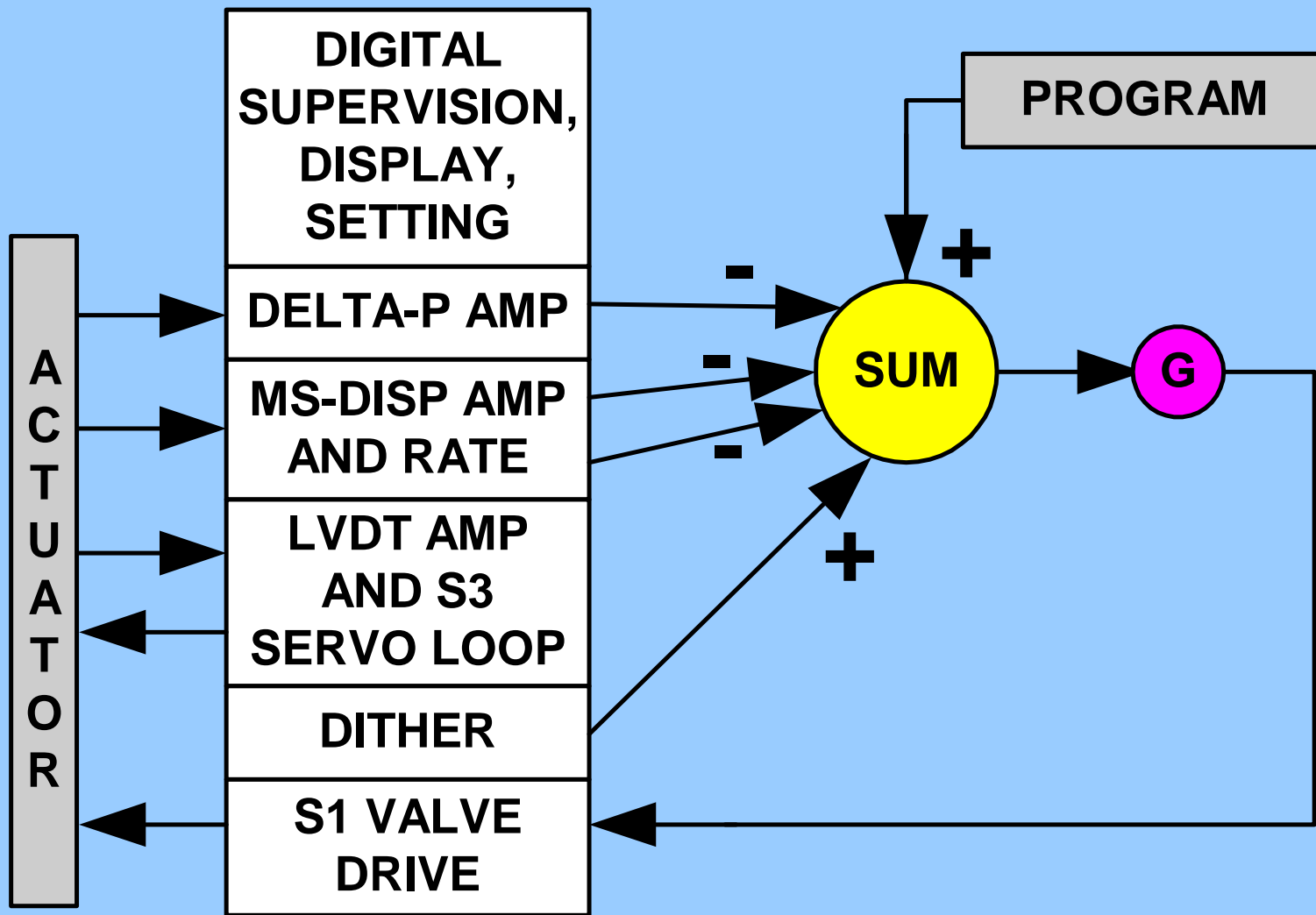
WHAT IS AN LVDT ?

- **A LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT) SENSES DISPLACEMENT BY NOTING THE CHANGE IN INDUCTANCE OF A COIL AS A METALLIC ROD IS PASSED THROUGH IT.**
- **LVDT'S WERE OFTEN USED IN ACTUATORS BUT LONG ONES HAVE INTERNAL WEAR AS THE ROD SCRAPES THE COIL TUBE. HENCE MAGNETOSTRICTIVE DEVICES ARE NOW PREFERRED.**

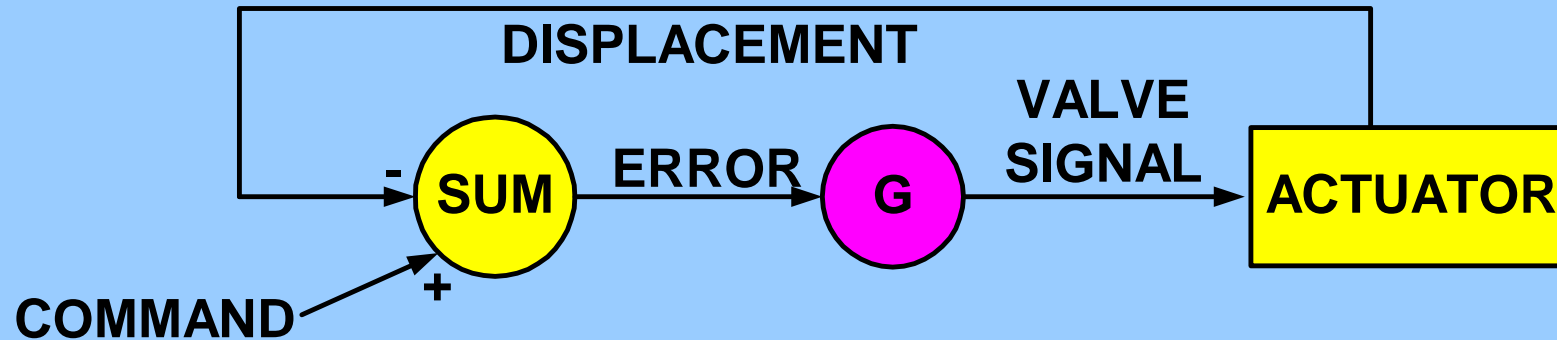
FLEX AND SUPER COLLAR



SERVO CONTROLLER

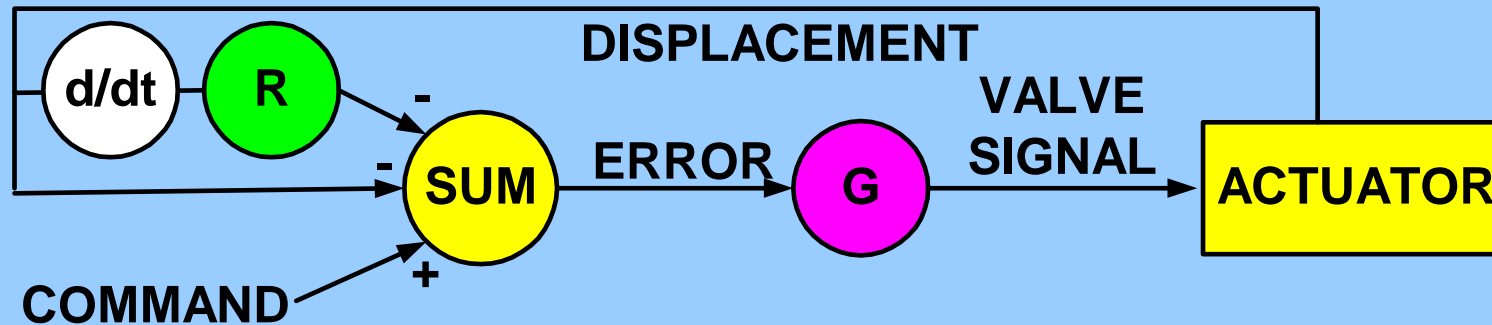


GAIN



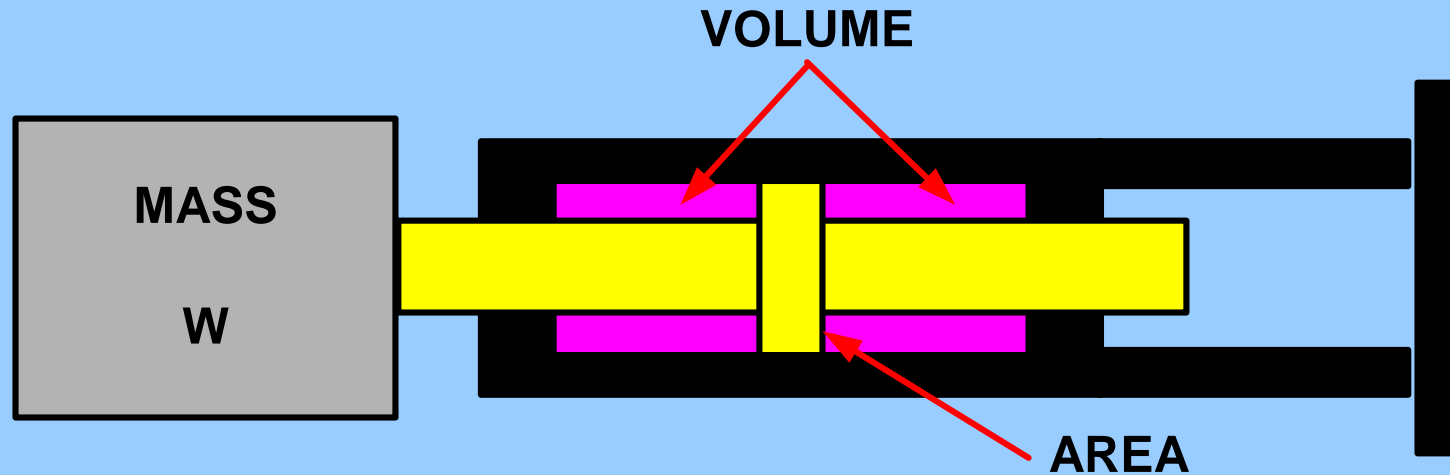
- A GAIN OF 1.0 MEANS THAT AN DISPLACEMENT ERROR OF 100% CAUSES THE VALVE TO OPEN 100%.
- A GAIN OF 1.0 – 3.0 IS TYPICAL
- TOO MUCH GAIN CAUSES OVER SHOOT AND INSTABILITY
- TOO LITTLE GAIN CAUSES A SOFT AND SLOPPY RESPONSE
- THE BEST GAIN DEPENDS ON TEST MASS AND DYNAMICS

RATE



- RATE FEEDS BACK A VELOCITY PROPORTIONAL SIGNAL TO REDUCE OVERSHOOT VELOCITY
- RATE ALLOWS STABILITY WITH HIGHER GAIN. TOO MUCH RATE CAUSES AN UNWANTED HIGH FREQUENCY INSTABILITY
- A RATE VALUE OF 50 IS TYPICAL AND DEPENDS ON TEST MASS AND DYNAMIC

OIL COLUMN RESONANCE AND DELTA-P

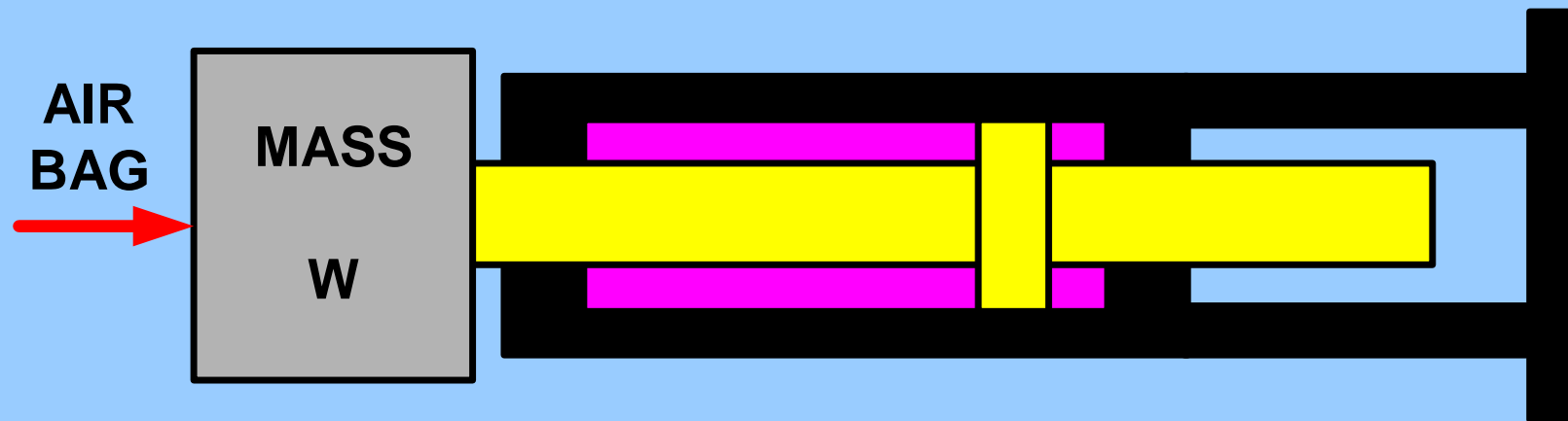


$$f \text{ (Hz)} = 2800 \times \text{AREA (SQUARE INCHES)} / \text{SQRT}(\text{WEIGHT (LBS)} \times \text{TOTAL VOLUME (CUBIC INCHES)})$$

- $f = 16 \text{ Hz}$ FOR R-149 WITH 10 TON MASS
- OTHER FLEXIBILITIES HAVE AN EFFECT

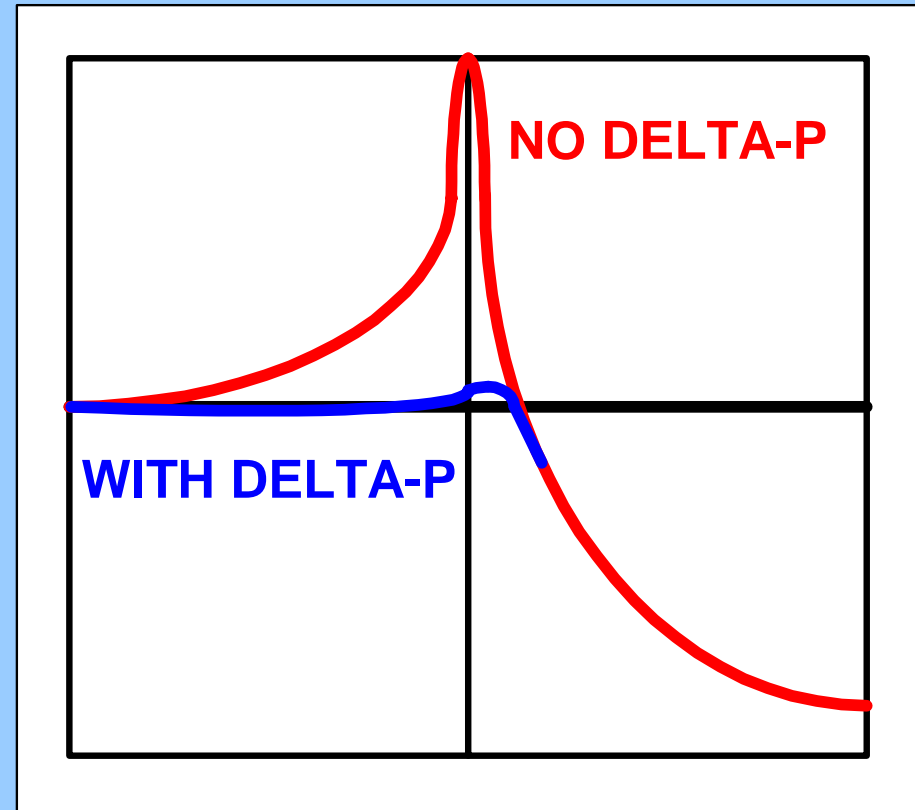
BIAS OPERATION

- **BIASED MODE OPERATION INCREASES THE OIL COLUMN RESONANCE BY SHORTENING THE OIL COLUMN**
- **THIS ALLOWS FOR BETTER CONTROL OF NARROW IMPULSES**
- **THE FORCE AND ACCELERATION CAPACITY IS REDUCED**



DELTA-P INTRODUCES ELECTRONIC DAMPING

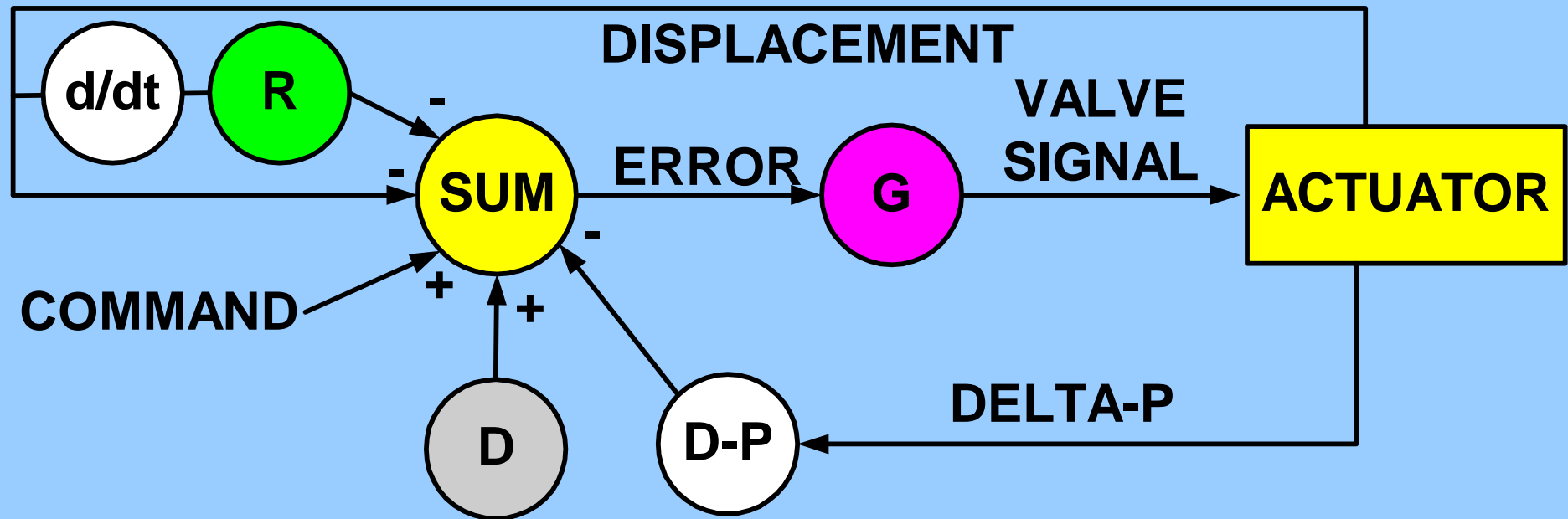
- WITH NO DELTA-P THE OIL COLUMN RESONANCE HAS LITTLE DAMPING AND WILL PRODUCE HIGH AMPLITUDE OSCILLATIONS AT THE OIL COLUMN FREQUENCY
- WITH DELTA-P THE RESONANCE STILL EXISTS BUT IS HIGHLY DAMPED AND CAN BE CONTROLLED



DITHER

- **THE STATIC FRICTION OF THE VALVE SPOOLS, ACTUATOR SEALS, AND TABLE BEARINGS IS GREATER THAN THE DYNAMIC FRICTION**
- **THIS CAUSES A STICKING AND JOLT IF THE ACTUATOR VELOCITY IS AT OR NEAR ZERO AND THEN MOTION IS REQUESTED (ALSO GRUMBLING)**
- **A 400 Hz SINUSOIDAL “DITHER” SIGNAL IS ADDED TO THE COMMAND SIGNAL TO MINIMIZE THIS PROBLEM**
- **MORE DITHER IS NEEDED AS THE VALVES BECOME MORE CONTAMINATED**
- **A TYPICAL VALUE FOR DITHER IS 30.**

THE FINAL SERVO LOOP



SERVO CONTROLLER ADJUSTMENT

- **THE GS 2000 SERVO CONTROLLER FRONT PANEL HAS A TOP, MIDDLE, AND BOTTOM SECTION**
- **THE TOP SECTION HAS A DIGITAL DISPLAY AND THE ABILITY TO SELECT THE VARIOUS PARAMETERS FOR DISPLAY**
- **THE MIDDLE SECTION ALLOWS SELECTION FOR ADJUSTMENTS OF THESE PARAMETERS**
- **THE BOTTOM SECTION HAS A ROTARY ENCODER THAT MAKES THE CHANGES**
- **THE GS 2000 IS A DIGITALLY SUPERVISED ANALOG SERVO CONTROLLER**

OTHER SERVO CONTROLLER PARAMETERS AND

- SPAN
- SET POINT
- UPPER LIMIT
- LOWER LIMIT
- ERROR DETECT
- ZERO



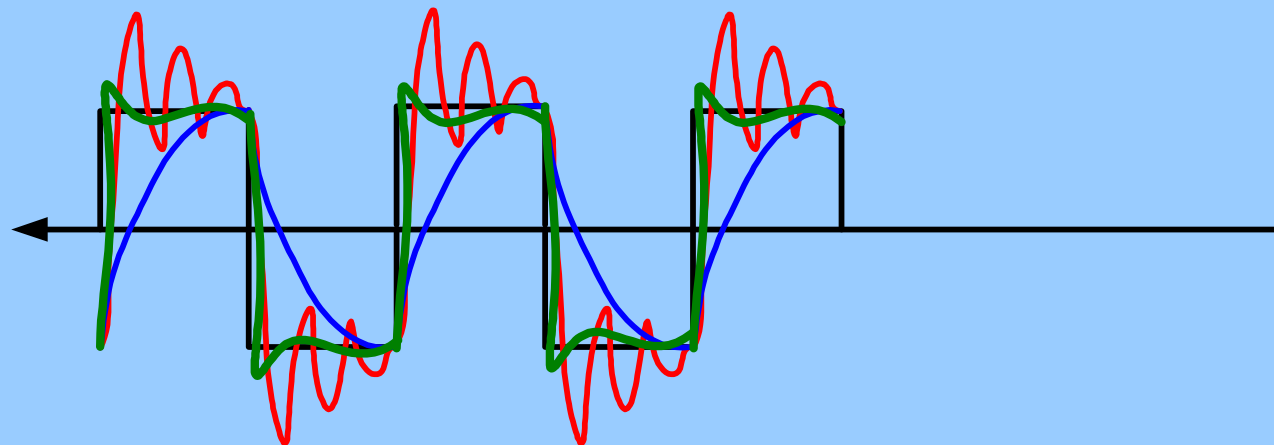
SC NOMENCLATURE

FOR THE R-149 NOTE

THE FOLLOWING MEANINGS OF NAMES

- XD1 IS THE DELTA-P SIGNAL ($\pm 100 = \pm 5000$ PSI)
- XD2 IS THE LVDT ON S3
- XD3 IS THE ACTUATOR DISPLACEMENT TRANSDUCER ($\pm 100 = \pm 9$ INCHES OR 229 mm)
- VALVE IS THE VALVE DRIVE SIGNAL ($\pm 100 = \pm 100\%$ OPEN)
- RESET IS THE DELTA-P GAIN
- PROGRAM IS THE COMMAND SIGNAL (± 10 V = $\pm 100 = \pm 9$ INCHES OR 229 mm)

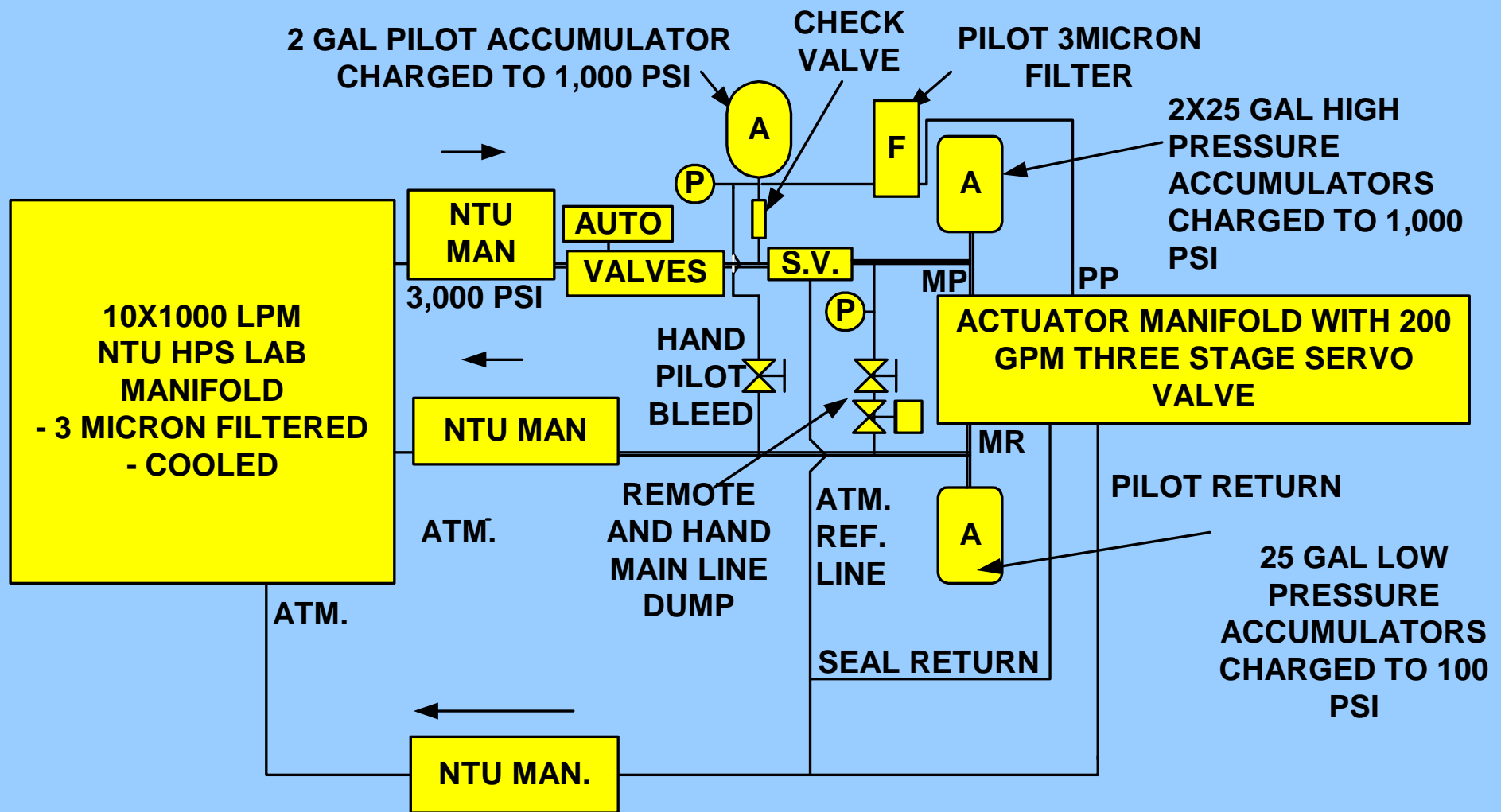
TUNING, SIGNAL GENERATOR



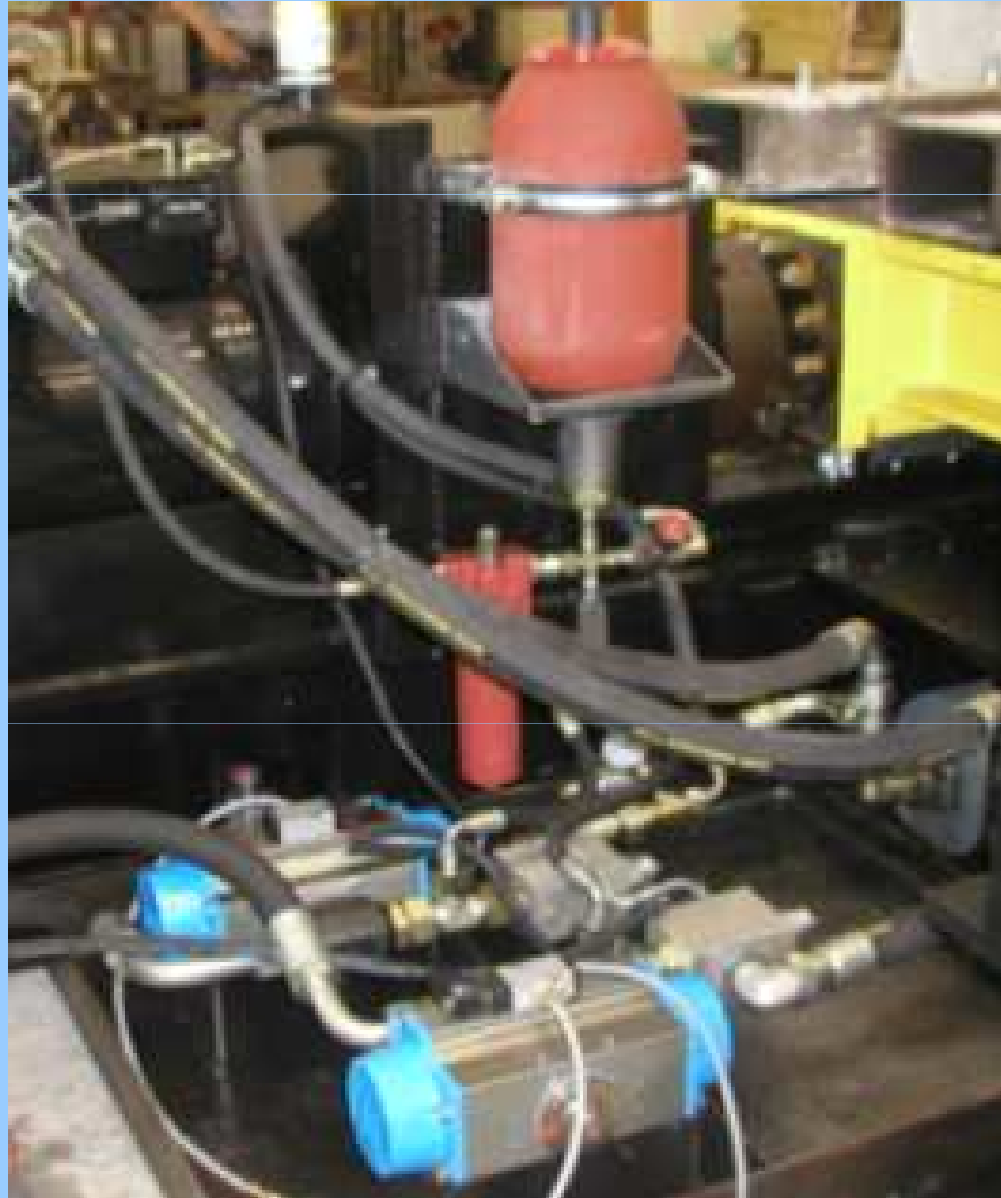
DISPLACEMENT (BY EYE OR OSCILLOSCOPE)

GOAL: ADJUST LOOP PARAMETERS TO GET
A CRISP A SQUARE WAVE AS POSSIBLE

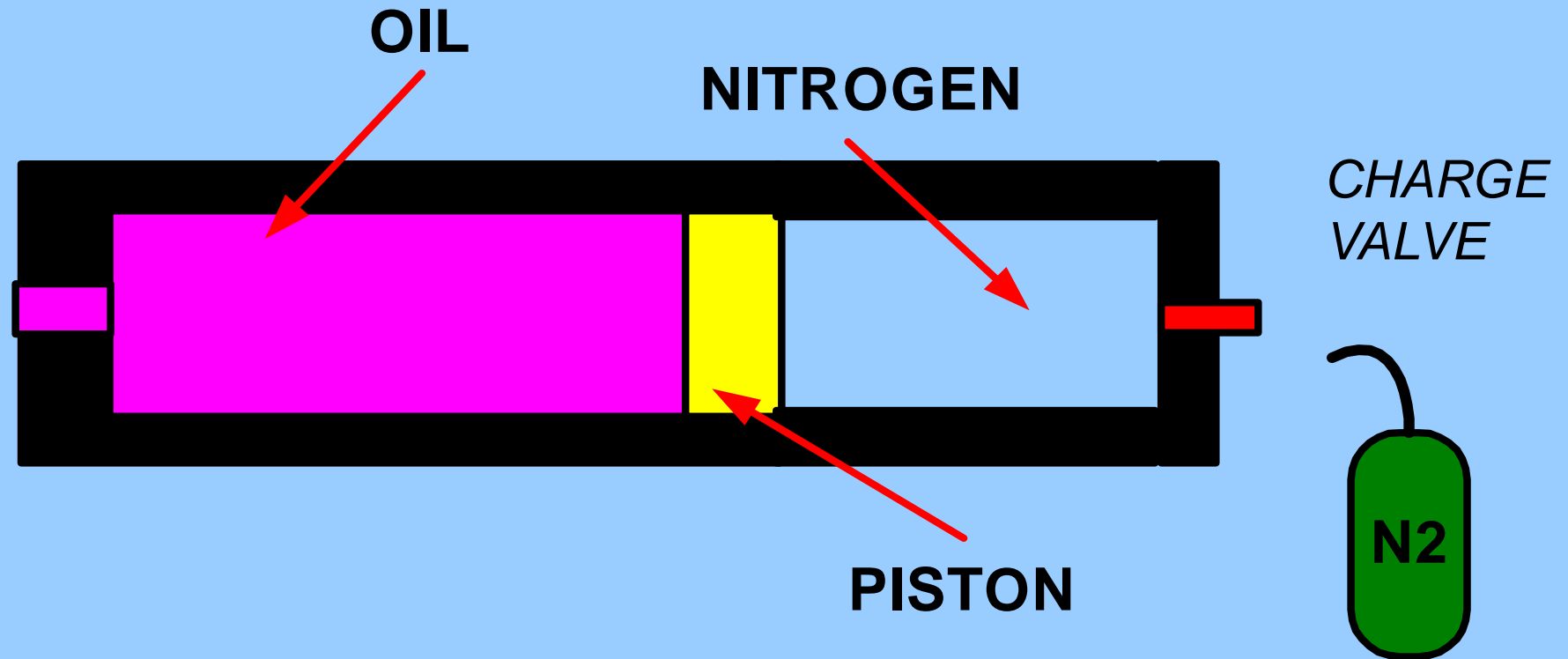
TABLE HYDRAULIC MANIFOLD



MANIFOLD



ACCUMULATORS



BLADDER OR DIAPHRAM CAN BE USED INSTEAD OF PISTON

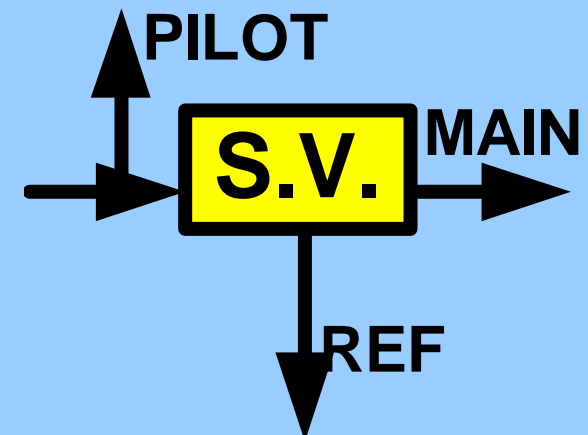
ACCUMULATORS ARE USED FOR ENERGY STORAGE, PEAK FLOW, HIGH FREQUENCY RESPONSE, AND PULSATION CONTROL

ISOLATION VALVES

- **THE TWO AIR OPERATED ISOLATION VALVES ARE NORMALLY CLOSED AND ARE OPENED ONLY BY THE START COMMAND IN THE CONTROL ROOM**
- **THEY SERVE TO ISOLATE THE R-149 FROM THE OTHER HYDRAULIC SYSTEMS AND PUMP IN THE LABORATORY**

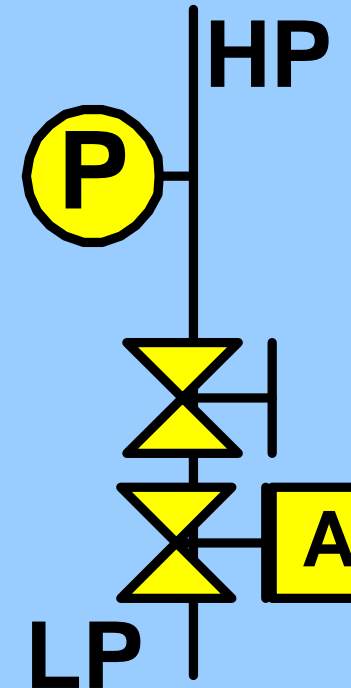
SEQUENCE VALVES

- TO MAINTAIN CONTROL THE PILOT (S2) VALVE MUST BE PRESSURIZED BEFORE THE MAIN (S3) VALVE.
- THE KICK-DOWN SEQUENCE VALVES DO NOT ALLOW FLOW TO THE MAIN VALVE UNTIL THE APPLIED PRESSURE EXCEEDS 1000 PSI.
- THEN THEY OPEN (KICK DOWN) AND ALLOW FLOW. THEY DO NOT CLOSE UNTIL THE APPLIED PRESSURE FALLS TO THE REFERENCE ATMOSPHERIC PRESSURE.



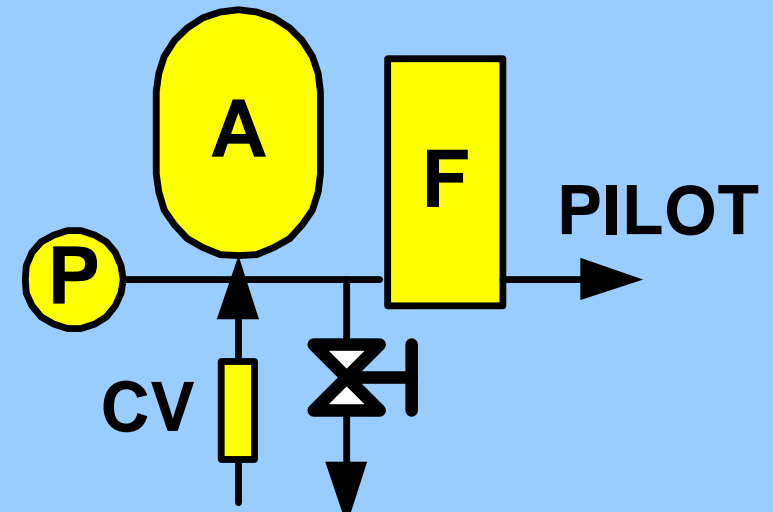
PRESSURE DUMP SYSTEM

- EVEN ON ISOLATION AND/OR PUMP STOP THERE IS A LARGE AMOUNT OF STORED ENERGY IN THE ACCUMULATORS – SUFFICIENT TO CONTINUE STRONG TABLE MOTION FOR 1-3 MINUTES.
- AN AUTOMATIC DUMP SYSTEM OPENS A VALVE ON SHUTDOWN THAT RELEASES THIS STORED ENERGY IN 10-30 SECONDS
- THERE IS A MANUAL OVERRIDE TO THIS SYSTEM



PILOT VALVE SYSTEM

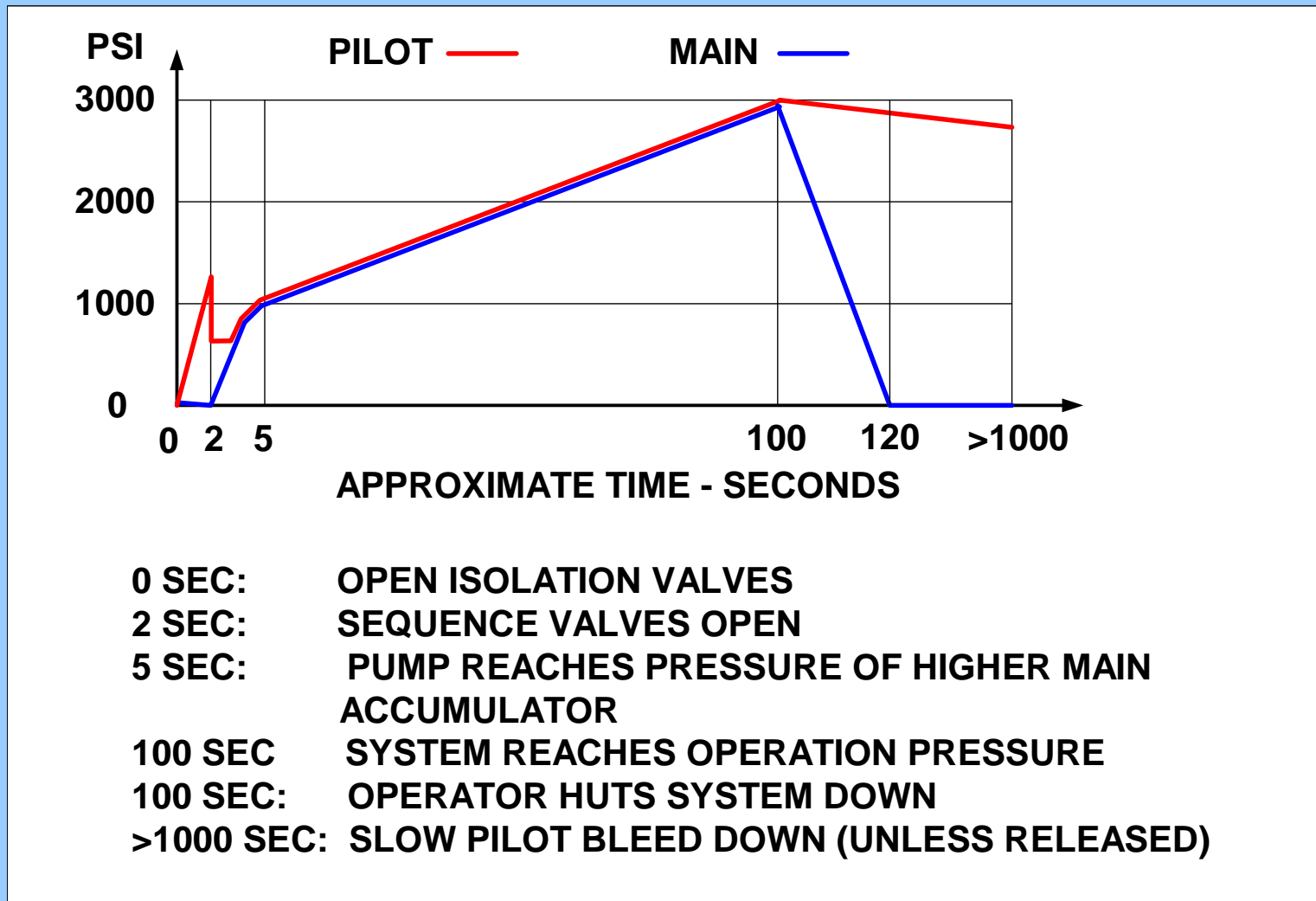
- THE PILOT VALVE SYSTEM ASSURES AN EARLY AND INDEPENDENT OIL SUPPLY TO THE PILOT VALVE
- CHECK VALVE
- ACCUMULATOR (1000 PSI CHARGE)
- PRESSURE GAGE
- HAND DUMP VALVE
- FILTER



PRESSURE GAGES AND OPERATION VERIFICATION

- **THE MAIN AND PILOT PRESSURE GAGES PROVIDE DETAILED SYSTEM OPERATING INFORMATION**
- **PUMP OPERATION**
- **SEQUENCE VALE**
- **PILOT ACCUMULATOR PRESSURE**
- **MAIN ACCUMULATOR PRESSURE**

PRESSURE GAGE INFORMATION



MAIN ACCUMULATORS

- **THERE ARE TWO 25 GALLON HIGH PRESSURE SIDE ACCUMULATORS CHARGED TO 1000 PSI. THEY STORE ENERGY FOR TRANSIENT EVENTS**
- **THERE IS ONE 25 GALLON LOW PRESSURE SIDE ACCUMULATOR CHARGED TO 100 PSI. IT ACCEPTS SURGE FLOW TO REDUCE BACK PRESSURE.**
- **ALL ACCUMULATORS HELP WITH LINE PULSATION CONTROL**

PILOT RETURN AND DRAINS

- **IN ADDITION TO THE MAIN RETURN LINES THERE ARE THE PILOT AND SEAL DRAIN RETURN LINES**
- **DO NOT INTERRUPT THE SEAL DRAIN LINES: DOING SO WOULD BLOW OUT THE ACTUATOR AND S3 VALVE LOW PRESSURE SEALS**

AIR BAG USE

- **THE AIR BAG ASSEMBLY IS USED TO BIAS THE ACTUATOR TO ALLOW NARROWER IMPULSE TESTING**
- **WHEN NEEDED THE AIRBAG IS ATTACHED TO THE BASE FRAME AND TABLE END**
- **DO NOT EXCEED 90 PSI (RELIEF SET AT 125 PSI)**
- **NOTE: SYSTEM IS RATED AT 330 POUNDS OF AXIAL FORCE PER PSI OF PRESSURE. NOMINAL PRESSURE IS 90 PSI (13.5 TONS)**



Module 4

DATA PHYSICS DIGITAL CONTROLLER/PC AND ANCO SPECTRUM SOFTWARE

DIGITAL CONTROL AND DATA ACQUISITION



PC

- **DELL PENTIUM 4**
- **2 GHz**
- **256 MB RAM**
- **CDRW, FLOPPY, MODEM**
- **15" LCD MONITOR**
- **WINDOWS XP OPERATING SYSTEM**
- **SIGNAL CALC SOFTWARE**
- **SPECTRUM COMPATIBLE SOFTWARE**

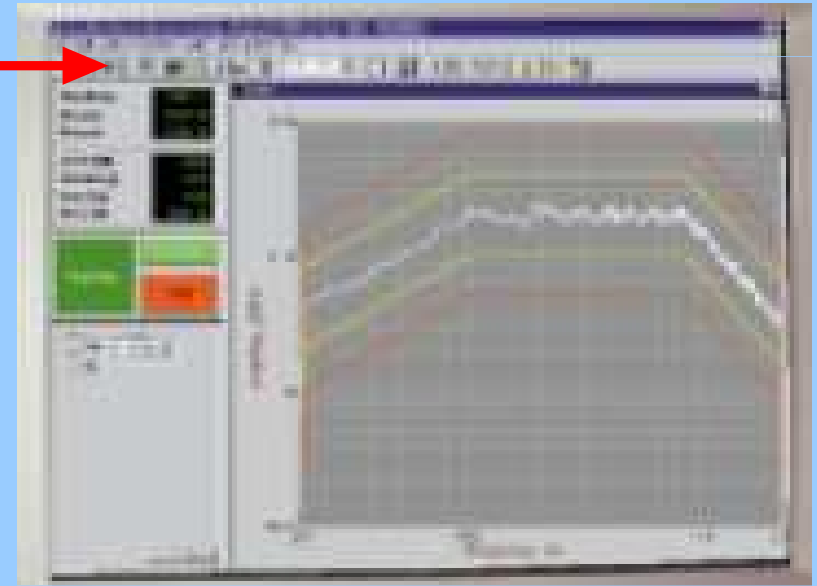


INPUT LIMITS, ICP

- **THE DRIVE VOLTAGE INPUTS TO THE DP ADC ARE MAXIMUM +/- 10 VOLTS WHICH NOMINALLY MAP TO +/-16 BITS**
- **DYNAMIC SCALING IS POSSIBLE**
- **THE ADC HAVE AN AC/DC OPTION**
- **THE ADC HAS AN ICP OPTION FOR PIEZOELECTRIC TRANSDUCERS**

SYSTEM SET UP SCREEN

- SHAKER AND EQUALIZATION SCREEN
- IMPORT SCREEN
- CALIBRATION AND ADC SCREEN
- NOTES SCREEN
- RUN SCREEN
- SLIGHTLY DIFFERENT FOR EACH DRIVE SIGNAL TYPE



EQUALIZATION AND SHAKER CONTROL SCREEN

- TOGGLE FOR SELF TEST OR LAST H
- SELF TEST LEVELS AND VOLTAGE LIMITS
- DRIVE VOLTAGE LIMITS
- SHAKER MAXIMUM X , X' , X''
- SHAKER LOWEST FREQUENCY
- COMPENSATION FREQUENCY
- FILTER
- RESPONSE SPECTRA SET UP
- ALARMS
- TYPE OF CONTROL

IMPORT SCREEN

- **DEFINE DRIVE SIGNAL**
- **TRANSIENT, IMPULSE, SINE, OR RANDOM**
- **E.G. – IMPORT ASCII EARTHQUAKE TIME HISTORY**
- **FLEXIBLE FORMAT**

CALIBRATION SCREEN

- **TRANSDUCER SENSITIVITY**
- **CONTROL CHANNEL(S) SELECTION**
- **LOCATION NAME**
- **AC/DC/ICP**
- **SCALE FACTOR**

NOTES SCREEN

- **TEST NAME**
- **TEST DATE**
- **OPERATOR NAME**
- **TEST OBJECT NAME**
- **COMMENTARY**

RUN SCHEDULER SCREEN

- **LEVEL OF TESTS**
- **NUMBER OF REPEATS**
- **DURATION**
- **FREQUENCY**
- **BLOCK CYCLING**

EQUALIZATION THEORY

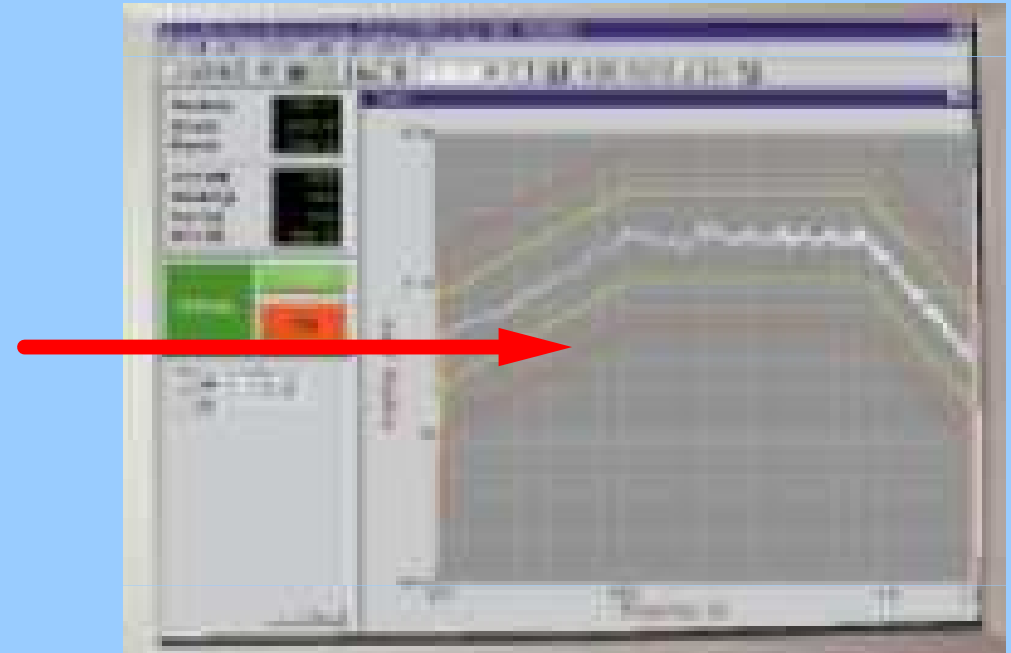
- **A1 = DESIRED TABLE ACCELERATION**
- **DP DRIVES TABLE WITH A1 (OR REDUCED VALUE OF A1)**
- **T1 = ACTUAL TABLE ACCELERATION**
- **COMPUTE $H1 = T1/A1$ THE TRANSFER FUNCTION OF THE TABLE**
- **LET $A2 = A1/H1$**
- **DRIVE THE TABLE WITH A2**
- **RESULT IS $T2 = H1 \times A2 = H1 \times A1/H1 = A1$ (APPROXIMATELY)**
- **ITERATE TO HANDLE NONLINEARITIES AND IMPROVE THE FIT**

DISPLACEMENT VERSUS ACCELERATION FEEDBACK

- THE GS SERVO CONTROLLER REQUIRES A DISPLACEMENT COMMAND
- THE DP DIGITAL CONTROLLER USES AN ACCELERATION COMMAND
- THIS DIFFERENCE IN EXPECTATION IS ADJUSTED FOR IN THE EQUALIZATION PROCESS (I.E. THE DRIVE SPECTRA IS DIVIDED BY $-f^2$)
- THIS REQUIRES THE SELF TEST TO START AT A LOW LEVEL (E.G. -30 db) TO AVOID OVERDRIVING THE TABLE

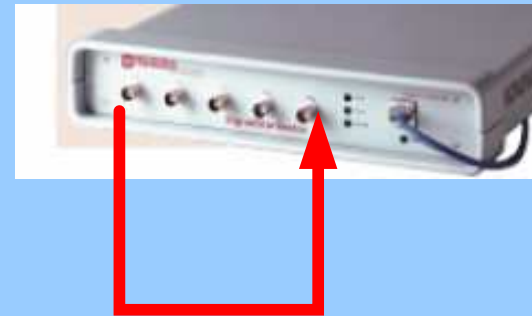
DATA DISPLAY AND EXPORT

- TIME DATA AND PROCESSED DATA SUCH AS INTEGRATED VALUES, TRANSFER FUNCTIONS, RESPONSE SPECTRA, AND COMMAND VALUES CAN BE PLOTTED IN VARIOUS FORMATS OR EXPORTED IN ASCII FORMAT



BARE WIRE TEST

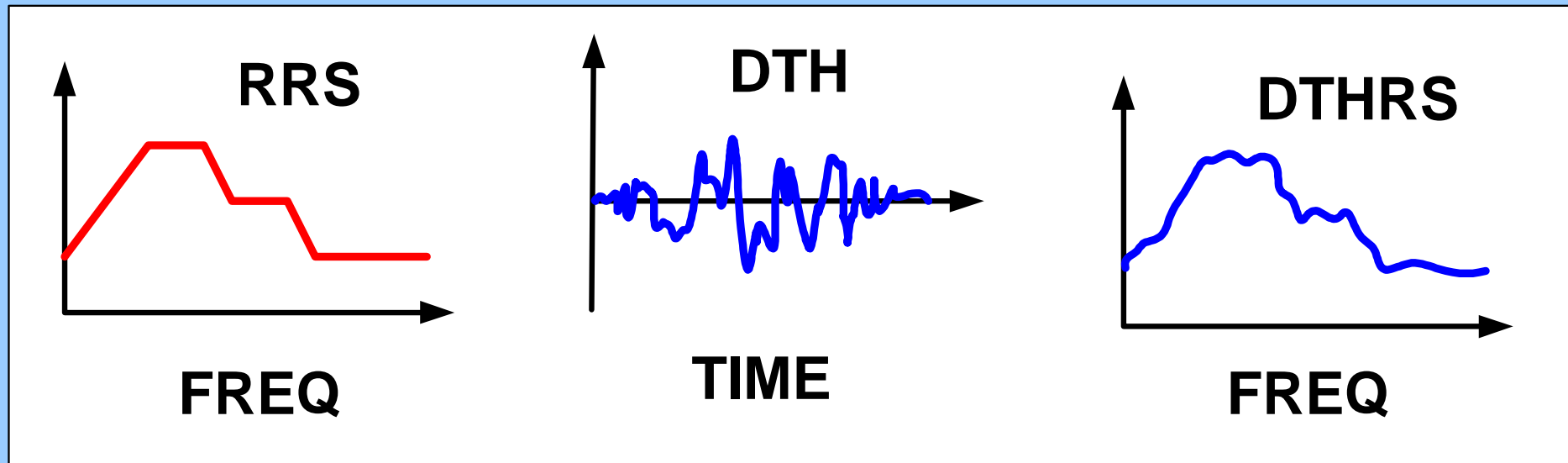
- THIS TEST ELIMINATES THE SHAKE TABLE AND IS VERY USEFUL FOR TRAINING AND DP TROUBLE SHOOTING
- THE DAC OUTPUT DRIVE SIGNAL IS CONNECTED DIRECTLY TO THE ADC INPUT FEEDBACK SIGNAL



SPECTRUM COMPATIBLE EARTHQUAKES

- **THE METHOD OF GASPARINI AND VANMARK IS USED TO CREATE A SPECTRUM COMPATIBLE TIME HISTORY**
- **THIS IS NOT A UNIQUE PROCESS AS DIFFERENT TIME HISTORIES CAN HAVE THE SAME RESPONSE SPECTRA**
- **THE PROCESS INVOLVES ITERATIONS WITH THE RESPONSE SPECTRA AND FOURIER TRANSFORM OF THE TIME HISTORY, WHICH STARTS AS A WHITE NOISE RANDOM SEQUENCE**

SPECTRUM COMPATIBLE EARTHQUAKE (CONTINUED)



ACCELEROMETERS, CABLES, AND BLOCKS

- THE R-149 COMES EQUIPPED WITH 3 DYTRAN MODEL 3187D PIEZOELECTRIC ACCELEROMETERS (500 MV/G NOMINAL CALIBRATION)
- A 12 CHANNEL DYTRAN AMPLIFIER (OR DP ICP OPTION) IS AVAILABLE
- THE ACCELEROMETERS HAVE AN OPERATING FREQUENCY FROM 0.5 Hz. TO OVER 1000 Hz.
- THERE IS A 2 m SHORT CABLE AND 70 m LONG CABLE (BNC) FOR EACH ACCELEROMETER. THEY ARE MARKED A1, A2, AND A3
- ALUMINUM MOUNTING BLOCK
- THEY ARE USEFUL FOR TABLE FEEDBACK AND STRUCTURAL RESPONSE MONITORING
- AVOID DROPPING OR SHOCKING THEM
- PERIODICALLY RECALIBRATE THEM

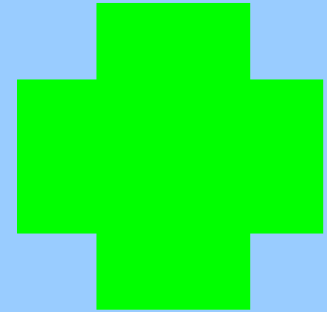
Module 5

SYSTEM SAFETY AND MAINTENANCE

CAUTION !

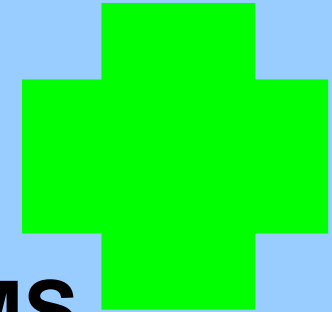
- **LIKE ANY POWERFUL MACHINE IMPROPERLY USED, THE R R-149 HAS THE POTENTIAL TO CAUSE SERIOUS INJURY OR DEATH**
- **IMPROPER USE CAN ALSO CAUSE COSTLY EQUIPMENT DAMAGE**
- **BE TRAINED IN ITS USE**
- **UNDERSTAND AND OBSERVE ALL SAFETY ISSUES**

SAFETY ISSUES



- HARD, FAST, POWERFUL
- PINCH POINTS
- EXCLUSION AREA
- HIGH OIL AND NITROGEN PRESSURE/FLOW
- HIGH ELECTRICAL VOLTAGE/POWER
- HEAVY WEIGHTS/CRANE
- ***ENGAGE BRAIN BEFORE TABLE !***

SAFETY ISSUES (CONTINUED)

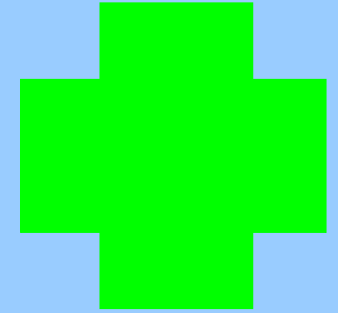


- **POTENTIALLY DAMAGED TEST ITEMS**
- **POTENTIAL TO OVERDRIVE**
- **SENSITIVE TO POWER OFF OR LOSS**
- **AUTOMATIC OPERATION**
- **INTERACTION WITH OTHER LAB SYSTEMS**
- **POTENTIAL EQUIPMENT DAMAGE**
- **REQUIRES TRAINED OPERATORS**
- **REQUIRES UPS**

RAUMOKO IS AN UNFORGIVING GOD !

SAFETY ISSUES

DESIGNED SAFETY FEATURES



- ELECTRONIC DISPLACEMENT LIMITS
- PC LIMITS ON MAX X , X' , X''
- PC LIMITS ON MAX DRIVE VOLTAGE
- AUTOMATIC DUMP AND ZERO PROGRAM ON SHUTDOWN OR E-STOP
- UPS
- SOFT/HARD STOPS
- FLASHING LIGHT ON ACTUATION
- ***DO NOT BYPASS THESE FEATURES !***

HYDRAULIC

- **MAKE SURE CONNECTIONS STAY TIGHT. ADDRESS ALL LEAKS**
- **PROTECT AND CHECK HOSES**
- **LOCK OUT PUMP IF SYSTEM IS OPENED**
- **CLEAN UP OIL LEAKS**
- **IN A MAJOR VENTING – WALK, DON'T RUN**

INTERACTION WITH OTHER LAB SYSTEMS

- **BE AWARE OF PUMP STATUS. ANCO STRONGLY RECOMMENDS AN IN LAB FLASHING LIGHT AND E-STOPS**
- **CLOSE 3 MANIFOLD VALVES WHEN NOT USING R-149 FOR EXTENDED PERIODS**
- **BE AWARE OF COMPETING FLOW DEMANDS, RETURN FLOWS, AND RESERVOIR LEVELS**
- **BE AWARE OF SMALL BUT POSSIBLE DYNAMIC INTERACTIONS**

ELECTRICAL

- **ALWAYS USE UPS**
- **BE AWARE OF POSSIBLE SHORTING TO TABLE DUE TO DYNAMIC DAMAGE OF TESTED COMPONENTS**
- **INSTALL GOOD GROUNDING**
- **PROTECT AND INSPECT CABLES AND CONNECTORS**

UPS SYSTEM

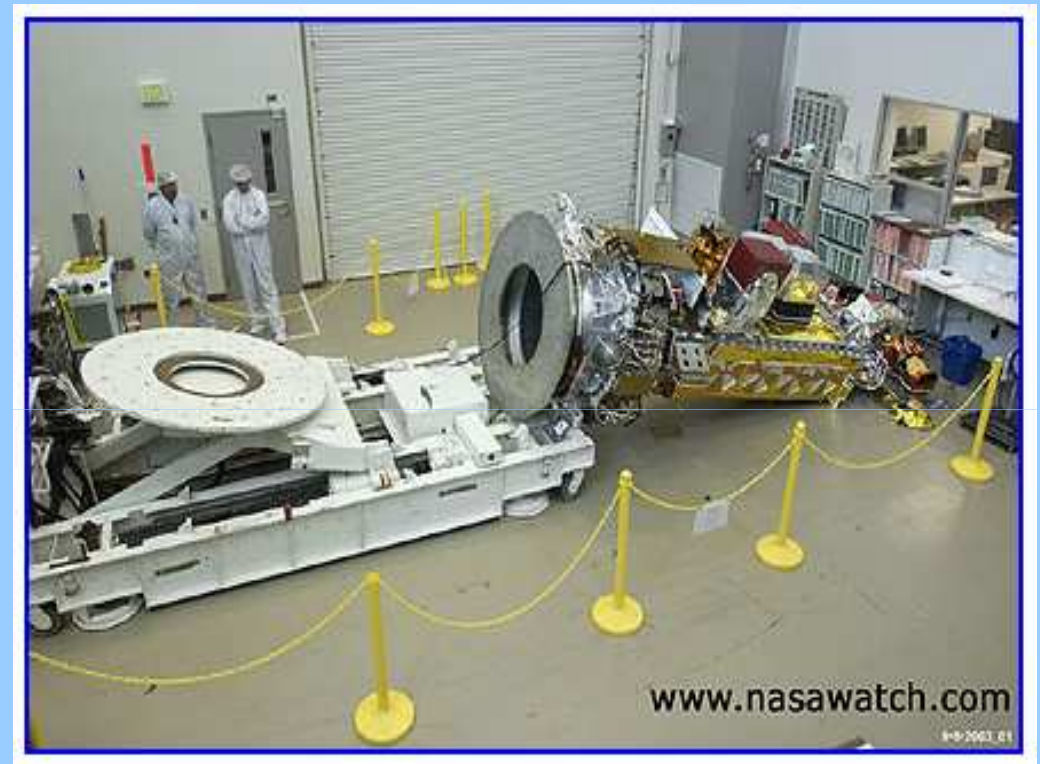
- ALWAYS USE UPS SYSTEM TO PROTECT AGAINST POWER GRID VARIATION OR FAILURE. LOSS OF POWER WITHOUT THE UPS WILL RESULT IN UNCONTROLLED TABLE MOTION
- CONNECT ONLY SERVO CONTROLLER, ACCELEROMETERS, DIGITAL CONTROLLER, PC, AND MONITOR
- NEVER TURN APPLY HYDRAULIC PRESSURE IF THE SERVO CONTROLLER IS NOT ON !
- SHUT DOWN WITHIN 3 MINUTES AFTER A POWER FAILURE
- TURN SYSTEM OFF IF LONG POWER FAILURES ARE POSSIBLE – THE DYING TRANSIENT OF THE UPS CAN DAMAGE ELECTRONICS

TESTING

- **TRIPLE CHECK COMMAND AND SERVO CONTROLLER SETTINGS AND BNC CONNECTIONS**
- **ALWAYS START WITH LOW DEMANDS AND WORK UPWARDS**
- **ANTICIPATE AND DEAL WITH POSSIBLE TEST ITEM FAILURE. PROTECT THE ACTUATOR.**
- **MAINTAIN AN EXCLUSION AREA**
- **LISTEN TO YOUR TABLE**

TESTING (CONTINUED)

- **MAKE SURE TEST OBJECT TO TABLE ANCHORAGE IS ADEQUATE**
- **NEVER ALLOW ANYONE ON THE TABLE IF ENERGIZED OR OPERATING**



SOFT/HARD STOPS

- **THE “SOFT” URETHANE STOPS ENGAGE AT +/- 190 mm**
- **AT +/- 200 mm THEY PROVIDE APPROXIMATELY 10 TONS COUNTER FORCE**
- **AT +/- 220 mm THEY PROVIDE APPROXIMATELY 40 TONS COUNTER FORCE**
- **AT +/- 220 MM THE STEEL HARD STOPS ENGAGE**
- **AVOID IMPACTING THE SOFT STOPS**
- **CAUTION – PINCH POINT !**

CRANE USE

- **USE ADEQUATE SLINGS AND LIFTING HARDWARE**
- **RIG CORRECTLY (E.G. WATCH TRANSVERSE LOADS ON EYE BOLTS)**
- **TAKE NOTE OF CRANE CAPACITY LIMITS**
- **MOVE SLOWLY. MAINTAIN EXCLUSION AREA**
- **HAVE ONE OPERATOR IN COMMAND – DO NOT ALLOW MORE THAN ONE PERSON FEEDING INFORMATION TO THE OPERATOR**

STRUCTURAL MARGIN ANALYSIS

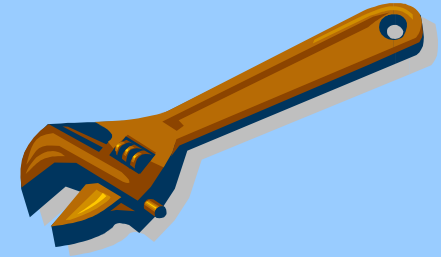
- **THE SYSTEM IS DESIGNED TO OPERATE AT 33% OF PEAK FORCES WITH MATERIAL STRESS UNDER THE ENDURANCE LIMIT**
- **THE DESIGN PROVIDES FOR 100% NORMAL FORCES UNDER THE ALLOWED MATERIAL WORKING STRESSES**
- **UNDER AN ACCIDENT SCENARIO (FULL HARD STOP IMPACT) THE LOADS ARE ABOUT 300% OF THE NORMAL FORCES. MATERIAL STRESSES ARE UNDER THE ULTIMATE**
- **HENCE MINIMIZE FULL FORCE OPERATION, AVOID ACCIDENT FORCES**

EQUIPMENT SAFETY

- **IMPROPER TABLE USE CAN CAUSE COSTLY EQUIPMENT FAILURE**
- **OVER DRIVING AND HARD STOP IMPACT CAN FAIL ACTUATOR, FLEX, OR BEARINGS**
- **CONTAMINATION CAN FAIL VALVES, FILTERS, AND PUMPS**
- **EXCEEDING 10 VOLT SIGNAL AMPLITUDE CAN FAIL ELECTRONICS**



MAINTENANCE



- **VALVE CLEANING**
- **ACCUMULATOR CHARGING/CHECKS**
- **BEARINGS GREASING/CHECKS**
- **FILTERS AND OIL CLEANLINESS**
- **ACTUATOR CARE/CHECKS**
- **ACTUATOR ALIGNMENT**

MAINTENANCE (CONTINUED)



- **BOLT AND CABLE TIGHTNESS**
- **ANCHORAGE INSPECTION**
- **FLEX AND TABLE TOP CARE**
- **ELECTRICAL CABLE CHECKS**
- **SPARE PARTS AND CONSUMABLES**
- **TABLE RELOCATION**
- **ELECTRONICS AS NEEDED**

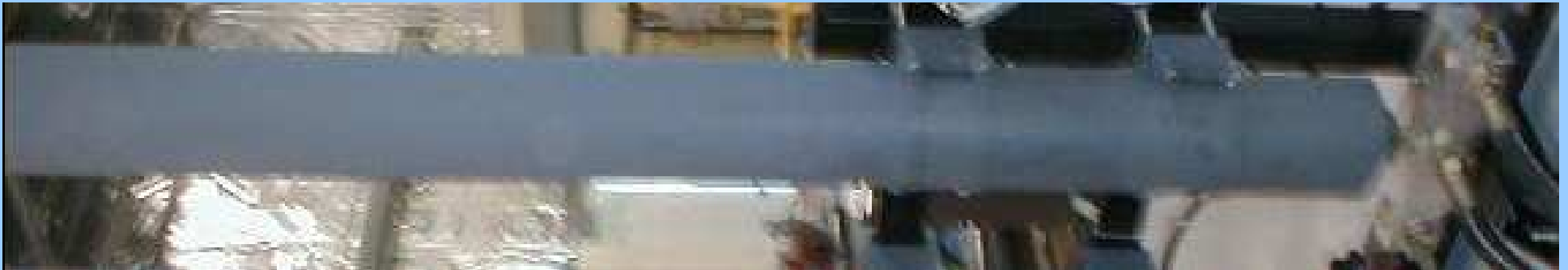
VALVE CLEANING (1 ASSEMBLY)

- ***S1/2 PILOT VALVES AND S3 MAIN VALVES CAN BE PROFESSIONALLY CLEANED IN SINGAPORE FOR ABOUT USD 800 EACH***
- ***S3 VALVES CAN BE CLEANED BY TRAINED NTU STAFF***
- ***S1/2 VALVES CAN BE PARTIALLY CLEANED BY TRAINED NTU STAFF***
- ***PROFESSIONAL CLEANING EVERY 2 YEARS OR AS NEEDED (WHEN CONTAMINATED) IS RECOMMENDED***



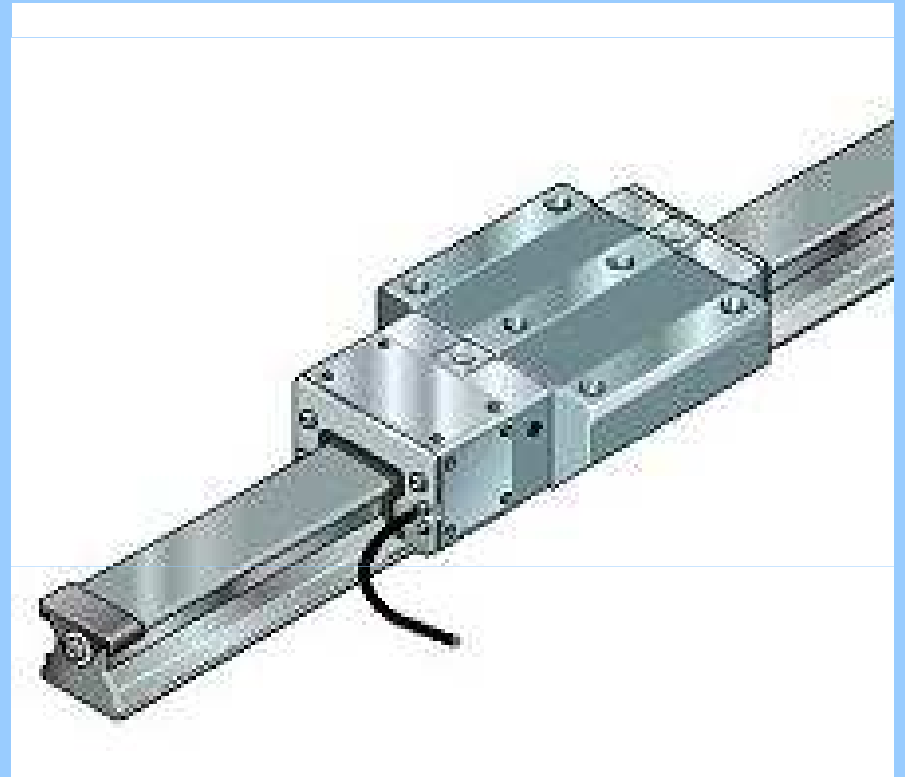
ACCUMULATORS (4)

- CHECK PRESSURE EVERY 30 DAYS OR WHEN TABLE USED
- RECHARGE AS NEEDED TO 100 OR 1000 PSI +/-20%
- THEY SHOULD HOLD PRESSURE FOR DAYS OR WEEKS
- REPLACE PISTON SEALS OR BLADDERS IF THEY LEAK FASTER
- USE ONLY DRY NITROGEN !
- BE CAREFUL WITH NITROGEN CYLINDERS !



BEARINGS (23)

- ***WIPE RAILS AND LUBRICATE BEARINGS EVERY 30 DAYS OR WHEN TABLE USED***
- ***USE HIGH QUALITY LITHIUM GREASE***
- ***USE GREASE GUN TO INJECT LUBRICANT UNTIL SOME SEAL BYPASS IS SEEN***
- ***AVOID NICKING RAILS***



FILTER (1) AND OIL CLEANLINESS

- **CHECK PILOT FILTER EVERY 30 DAYS DURING OPERATION. IF BUTTON STAY UP REPLACE FILTER ELEMENT**
- **FOLLOW ALL SPECIFIED FILTER MAINTENANCE FOR THE HPS**
- **TAKE STRONG ANTI-CONTAMINATION MEASURES WHEN OPENING HOSES OR VALVES**
- **KEEP THE TABLE GENERALLY FREE OF DUST AND DIRT**

ANTI-CONTAMINATION MEASURES

- **NEVER LAY HOSES ON FLOOR WITHOUT CLEAN CLOTH, PLASTIC OR PAPER UNDER CONNECTORS. OR USE METAL OR PLASTIC HOSE PLUGS**
- **COVER ANY OPEN PORTS WITH CLEAN CLOTH, PLASTIC, OR PAPER**
- **DO NOT EAT OR SMOKE WHILE SERVICING OPEN PORTS**
- **CLEAN HANDS WELL BEFORE SERVICING**
- **DISCARD ANY CONTAMINATED OIL – DO NOT REUSE**
- **NEW OIL IS DIRTY !**
- **YOU CAN NOT SEE 10 MICRON DIRT !**

ACTUATOR CARE

- **AVOID ANY NICKING OR CONTAMINATION OF THE PISTON ROD**
- **AVOID IMPACTS TO THE VALVES OR DISPLACEMENT TRANSDUCER**
- **IF MOVED THE ACTUATOR MUST BE RE-ALIGNED WITH THE TABLE. THE DIFFERENTIAL RUN-OUT MUST BE LESS THAN +/- 0.3 Mm OVER THE +/- 200 mm TRAVEL**
- **BOLT THE FLEX AT MID STROKE SO AS TO MINIMIZE BINDING THE PISTON**

BOLT TIGHTNESS

- **INSPECT AND RETIGHTEN ALL BOLTS AND NUTS TO THE RECOMMENDED TORQUE PERIODICALLY (SEE MANUAL OR CHARTS)**
- **PROPER TORQUE IS ESSENTIAL. LOCK WASHERS AND THREAD LOCKER ARE NOT RECOMMENDED**

NOMINAL BOLT TORQUES

BOLT DIA (mm)	T (N-M)
6	10
8	25
10	50
12	90
14	150
16	220
18	310
20	410
22	550
24	730
26	930
28	1150
30	1400

ANCHORAGE INSPECTION

- **EVERY 6 MONTHS OR AFTER VERY HIGH LEVEL TESTING CHECK THE TORQUE ON THE 23 SUPER-NUTS BELOW THE LABORATORY FLOOR**
- **THE 12 STUDS PER SUPER-NUT SHOULD HAVE A MINIMUM TORQUE OF 35 FT-LB WHEN TIGHTENED IN A STAR PATTERN**
- **REQUIRES A 5/16" SOCKET**

HOSE TIGHTNESS AND TYPES

- **THE SYSTEM HAS NUMEROUS JIC 37 DEGREE FITTINGS IN CABLE SIZES FROM #4 TO #20 (E.G. A #20 IS 20/16" = 1.25" = 32 mm INSIDE DIAMETER)**
- **THERE ARE SOME PIPE THREADS AND SAE O-RING CONNECTORS**
- **TORQUE THESE USING AN APPROPRIATE SIZED WRENCH AND MODERATE TO HIGH HAND FORCE**
- **OIL WEEPING MAY BE ACCEPTABLE, MORE THAN 1 DRIP PER MINUTE IS NOT**

CABLE CARE

- 80% OF TABLE CONTROL FAILURES ARE DUE TO DAMAGED CABLES OR CONNECTORS
- CHECK CABLES AND CONNECTORS PERIODICALLY FOR WEAR OR DISTRESS AND REPAIR AS NEEDED
- CHECK CONNECTOR TIGHTNESS
- MAINTAIN CABLE SLACK

FLEX COLLAR INSPECTION AND CARE

- **INSPECT THE FLEX COLLAR ONCE EVERY 3 MONTHS.**
- **CHECK FOR FATIGUE CRACKS IN FLEX**
- **CLEAN AND APPLY A COATING OF GREASE FOR CORROSION PREVENTION**
- **MAKE SURE BOLTS ARE TIGHT**
- **MAKE SURE THERE IS A 0.5 mm MINIMUM GAP BETWEEN THE SUPER COLLAR AND THE FLEX**

TABLE TOP CARE

- **AS NEEDED, CLEAN WITH STEEL WOOL, RE-BLUE WITH A CLOTH, AND APPLY A COATING OF OIL TO RETARD CORROSION. IN HIGHLY CORROSIVE AREAS USE GREASE.**
- **USE ONLY THE TAPPED HOLE GRID FOR ANCHORAGE. AVOID TAPPING NEW HOLES OR WELDING.**
- **USE TRANSITION PLATES TO AVOID NEEDING ADDITIONAL TAPPED HOLES**
- **PROTECT SURFACE WITH PLASTIC IF TESTING ROUGH OR CORROSIVE SYSTEMS**

ELECTRONIC SYSTEMS AND PC

- **THESE SYSTEMS REQUIRE NO PERIODIC MAINTENANCE OTHER THAN PERIODIC DUSTING AND SOLVENT WIPING**
- **ON MALFUNCTION REFER TO THE EQUIPMENT MANUAL OR PROFESSIONAL REPAIR SERVICES**
- **OFTEN THE PROBLEM IS A LOOSE CABLE OR UNSEATED BOARD – CHECK THESE FIRST**
- **THE CMOS BATTERY IN THE SERVO CONTROLLER AND PC MUST BE CHANGED, AS NEEDED**

RELOCATION OF TABLE

- **THE TABLE CAN BE RELOCATED BY RELEASING ITS ANCHORAGE AND RECONNECTING ITS HOSES AND CABLES (EXTENSIONS MAY BE REQUIRED)**
- **THE TABLE TOP MUST BE SEPARATELY MOVED DUE TO CRANE CAPACITY LIMITATIONS**
- **RELOCATION REQUIRES APPROXIMATELY 1 MAN MONTH**

TOOLS, SPARE PARTS AND CONSUMABLES

- **GREASE AND GREASE GUN**
- **FUSES**
- **ASSORTED NUTS, BOLTS, AND WASHERS**
- **SPECIAL WRENCHES**
- **ACCUMULATOR AIR VALVES (SPECIAL
HIGH PRESSURE UNITS)**
- **TOUCH UP PAINT**
- **BLUEING**
- **FILTER ELEMENT**
- **TOOL BOX**