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ADVANCED MAGNETIC SUSPENSIONS for VIBRATION ISOLATION and FAST-ATTITUDE CONTROL of SPACE-BASED GENERIC POINTING MOUNTS

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B-12112
EG-02086

DESIGN CRITERIA FOR GENERIC POINTING MOUNTS

- POINTING PAYLOAD:
  - SMALL (ounces)
  - LARGE (tons)
- AUTOMATICALLY ADAPT SERVO SYSTEM CONTROL LAWS TO INTERCHANGEABLE PAYLOADS
- CONTINUOUSLY ADAPT CONTROL LAWS TO POINTING ERRORS (POSITION, VELOCITY & ACCELERATION)
- ARTICULATION ANGLES UP TO 240 DEGREES
- TRANSMIT POWER/COMMANDS/DATA TO PAYLOAD WITHOUT CABLES
- MINIMIZE DATA RATE REQUIREMENT FOR INTERFACING WITH SPACE CRAFT

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WEG-06751

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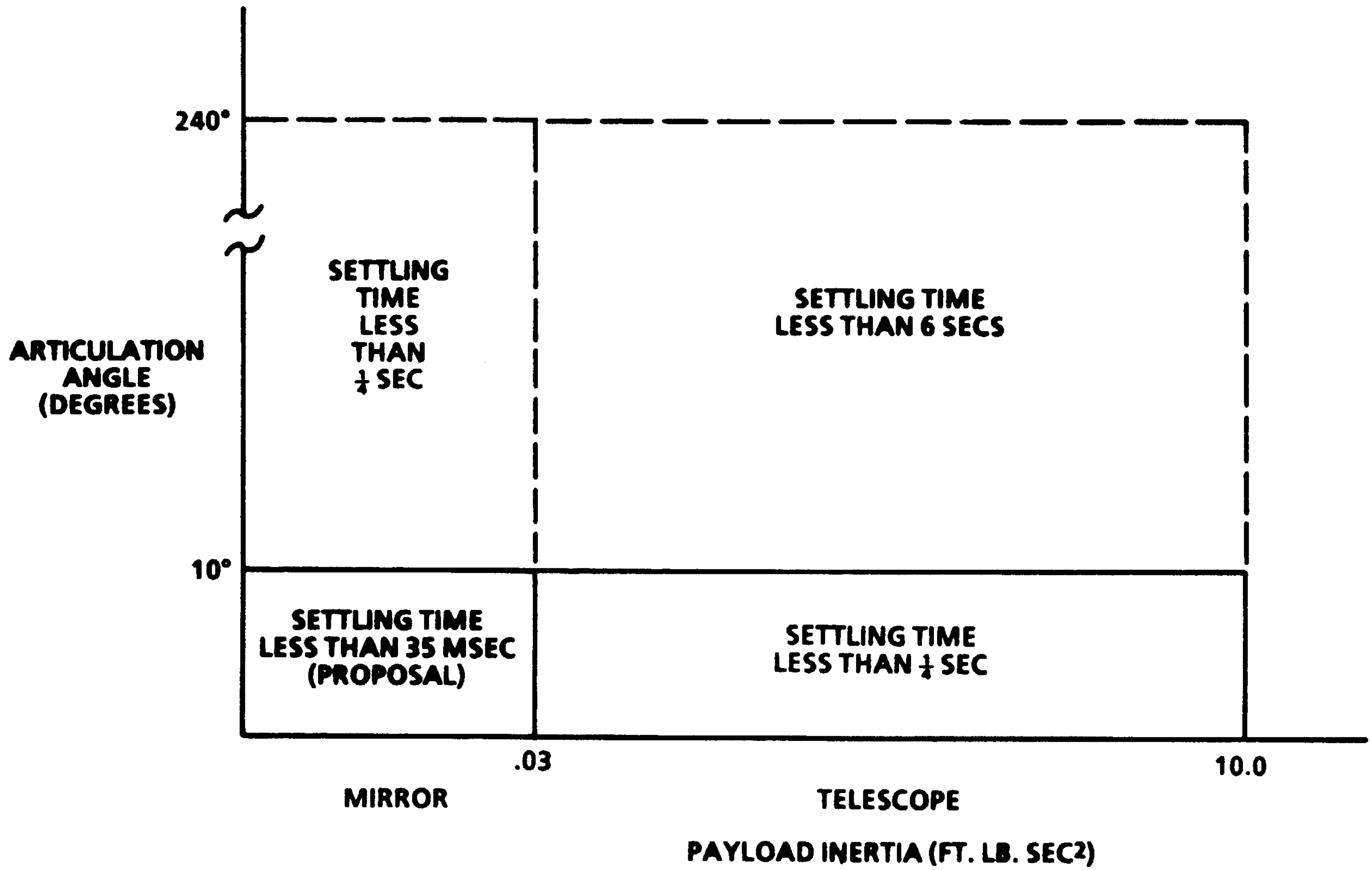
DESIGN CRITERIA FOR GENERIC POINTING MOUNTS

THE GENERIC POINTING MOUNT IS DESIGNED TO AIM A VARIETY OF INTERCHANGEABLE POINTING PAYLOADS USING MAGNETIC SUSPENSION AND ADAPTIVE CONTROL TECHNOLOGIES. TO CHANGE PAYLOADS REQUIRES ONLY THE MECHANICAL DETACHMENT OF THE OLD PAYLOAD AND THE ATTACHMENT OF THE NEW PAYLOAD. THE MOUNT'S SERVO SYSTEM AUTOMATICALLY SENSES THE CHANGE IN THE PAYLOAD AND MEASURES THE MULTIAXIS INERTIAS AND RESONANT CHARACTERISTICS OF THE NEW PAYLOAD. THE SERVO SYSTEM AUTOMATICALLY AND CONTINUOUSLY ADAPTS THE SERVO CONTROL LAWS TO OPTIMIZE THE ISOLATION OF THE PAYLOAD FROM SPACECRAFT VIBRATIONS, TO OPTIMIZE THE DAMPING OF PAYLOAD RESONANCES, AND TO MINIMIZE THE POINTING ERROR SETTLING TIMES FOR EACH INTERCHANGEABLE PAYLOAD AND AS THE VARIOUS MULTIAXIS POINTING ERRORS CHANGE WITH TIME. THE TRANSMISSION OF POWER AND COMMANDS TO THE PAYLOAD AND THE TRANSMISSION OF DATA FROM THE PAYLOAD ACROSS THE MAGNETIC SUSPENSION GAP IS ACCOMPLISHED WITHOUT THE USE OF CABLES. ARTICULATION IN TIP, TILT AND ROLL AXES ALLOWS 75% OF THE SPHERICAL SKY TO BE WITHIN THE MOUNTS AIMING CONE. DATA COMMUNICATION RATES BETWEEN THE POINTING MOUNT AND THE SPACECRAFT ARE MINIMIZED BY USE OF ARTICULATED AND NON ARTICULATED INERTIAL MEASUREMENT UNITS (IMU'S) COUPLED TO SPACECRAFT ORBIT AND ATTITUDE COMPUTATIONAL UNITS.

WHY IS THE PROPOSED DESIGN GENERIC?



*SETTLING TIME IS FOR SIX ORDERS OF MAGNITUDE ERROR REDUCTION

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WHY IS THE PROPOSED DESIGN GENERIC?

THE PROPOSED MOUNT IS GENERIC IN THAT IT CAN AIM EITHER LOW OR HIGH INERTIA PAYLOADS OVER REQUIRED ARTICULATION ANGLES THAT CAN RANGE FROM A FEW DEGREES TO 240 DEGREES. VARYING PAYLOAD INERTIA OR ARTICULATION ANGLE DOES AFFECT POINTING ERROR SETTLING TIME BUT DOES NOT AFFECT POINTING ACCURACY OR STABILITY. POINTING ERRORS CAN BE REDUCED BY SIX ORDERS OF MAGNITUDE FOR A MIRROR PAYLOAD HAVING AN INITIAL POINTING ERROR OF 10 DEGREES IN ONLY 35 MILLISECONDS. AS SHOWN, THE SETTLING TIME FOR THE MOST DEMANDING CONDITION (HIGH INERTIA, LARGE ARTICULATION ANGLE) DOES NOT EXCEED 6 SECONDS.

GENERIC POINTING MOUNT SYSTEM FEATURES

MEASURING PAYLOAD MECHANICAL IMPEDANCES	AUTOMATIC
CHANGING CONTROL LAWS TO MATCH PAYLOAD	STANDARD (IN SPACE)
VIBRATION ISOLATION	MASS DAMPING
VIBRATION DAMPING APPROACH	INERTIA VELOCITY ANTI-NODAL DAMPING FOR ALL PAYLOAD RESONANT MODES
MAXIMUM ARTICULATION ANGLE (TIP & TILT)	240°
POWER TRANSMISSION TO PAYLOAD	MICROWAVE
COMMANDS TO AND DATA FROM PAYLOAD	OPTICAL
GIMBALS	MAGNETIC
NUMBER OF PIVOT POINTS	ONE

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GENERIC POINTING MOUNT SYSTEM FEATURES

MOST OF THE FEATURES DESCRIPTIONS ARE SELF-EXPLANATORY, EXCEPT FOR VIBRATION ISOLATION AND VIBRATION DAMPING. CONVENTIONAL MAGNETIC SUSPENSIONS USE A PSEUDO VELOCITY SIGNAL (DERIVED BY LIMITED GAIN DIFFERENTIATION OF THE MEASURED GAP ACROSS THE SUSPENSION) IN THEIR CONTROL LOOPS TO ACHIEVE DAMPING OF STRUCTURAL RESONANT MODES. THEY ALSO USE SINGLE POINT IMPEDANCE CONTROL. THE GENERIC POINTING MOUNT USES THE INERTIALLY REFERENCED VELOCITY OF THE PAYLOAD TO ACHIEVE DAMPING AND USES AN APPROACH THAT EFFECTIVELY DAMPS ALL MODES AT THEIR ANTINODES REGARDLESS OF MODE SHAPE.

GENERIC POINTING MOUNT PERFORMANCE CHARACTERISTICS

PARAMETER	
SETTLING TIME: (10 TO $3X10^{-6}$ DEG)	0.0463 SEC
NUMBER OF CYCLES TO STEADY STATE	0.50 CYCLE
SLEW RATE	26.2 RAD/SEC
BANDWIDTH	
TRANSLATION RELATIVE TO INERTIAL FRAME	100 HZ
TRANSLATION RELATIVE TO PLATFORM	0.02 HZ
TIP	47.7 TO 450 HZ
TILT	47.7 TO 450 HZ

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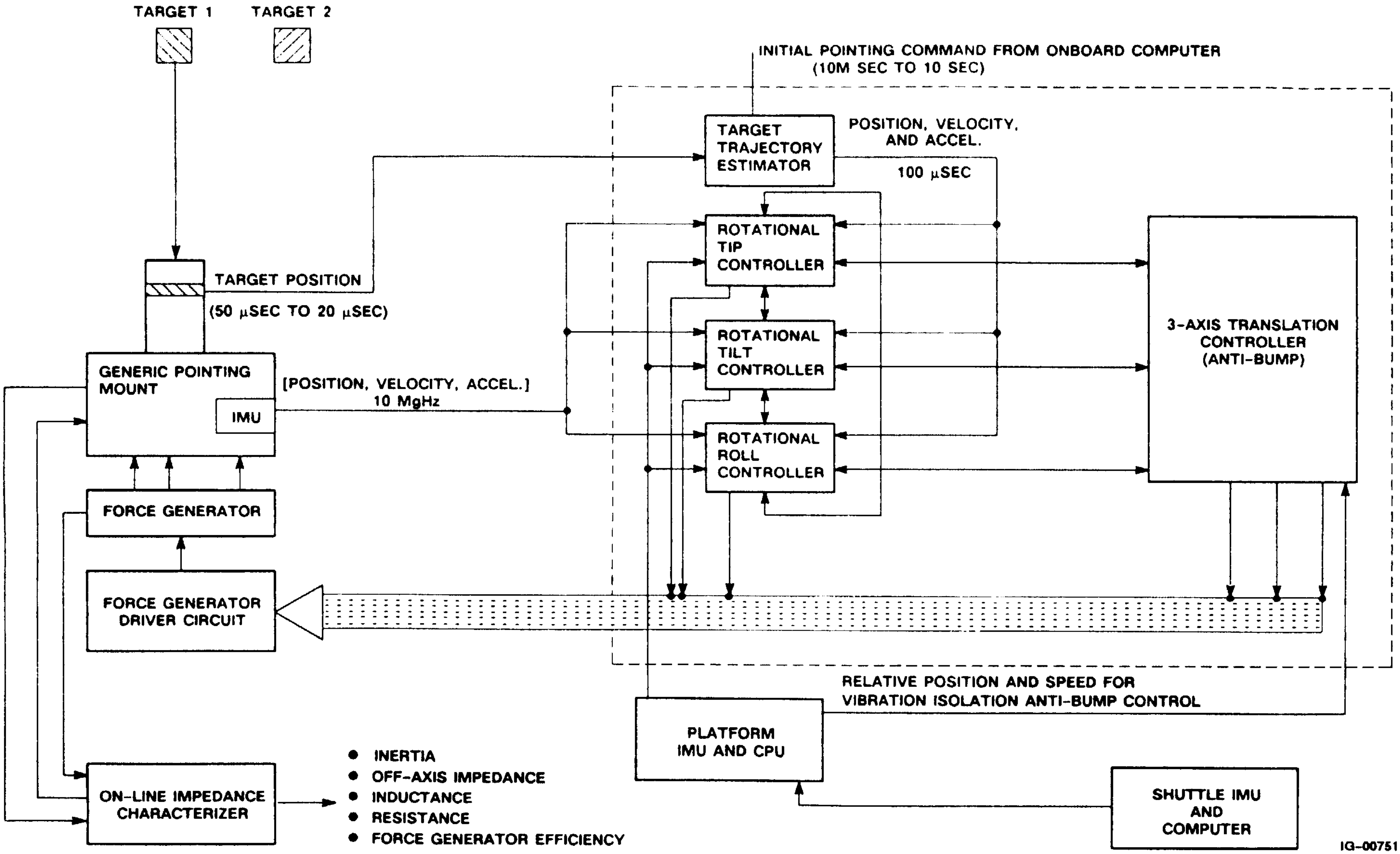
GENERIC POINTING MOUNT FUNCTIONAL BLOCK DIAGRAM



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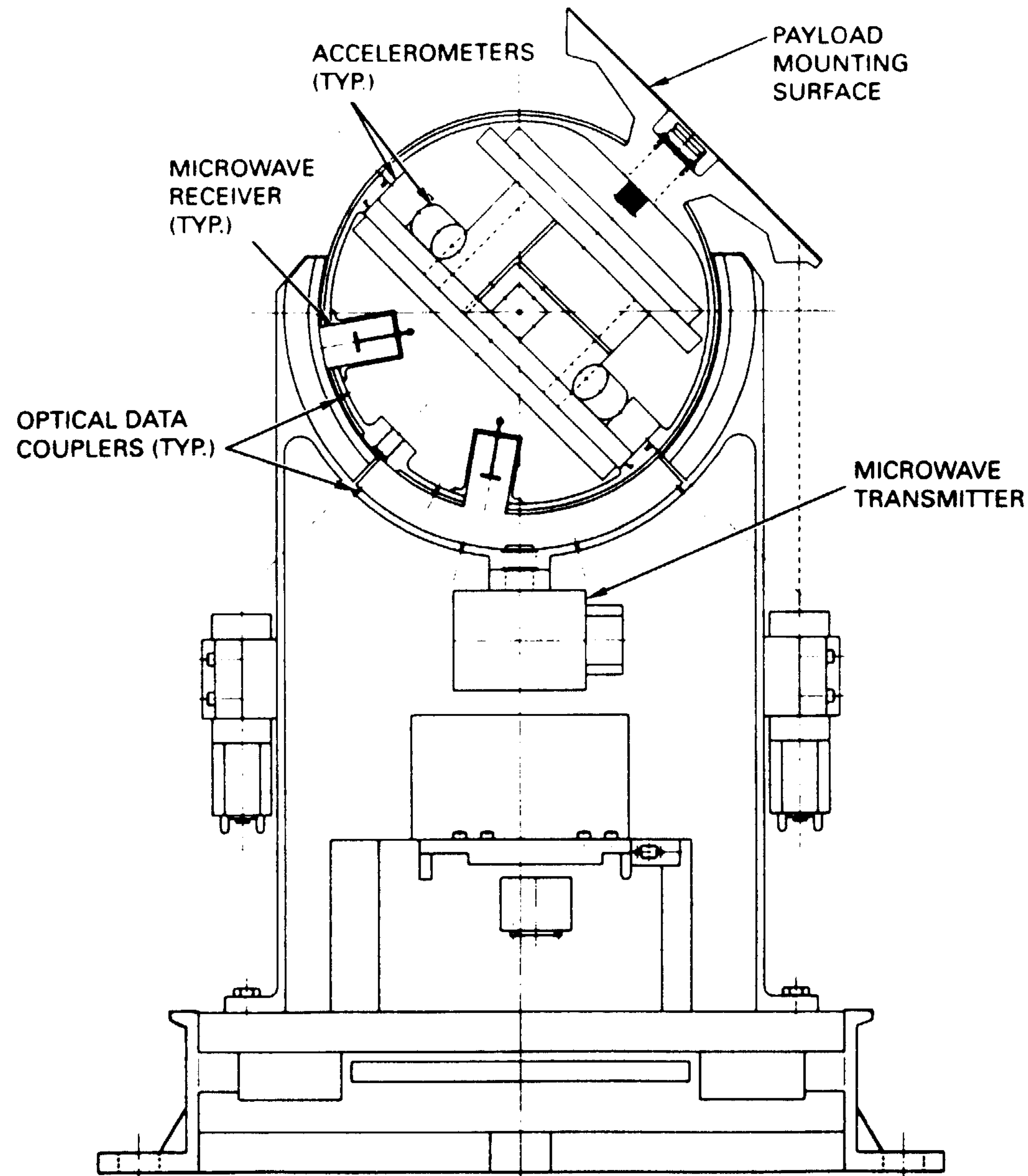
GENERIC POINTING MOUNT FUNCTIONAL BLOCK DIAGRAM

THE GENERIC POINTING MOUNT USES A SIX AXIS SERVO CONTROL TO ACHIEVE THE PROPER POINTING ANGLES AND TO PREVENT TRANSMISSION OF VIBRATION TO THE PAYLOAD. IT REQUIRES AN ARTICULATED IMU THAT MOVES WITH THE PAYLOAD. TO MINIMIZE THE NEED FOR SPACECRAFT ORBITAL AND ATTITUDE DATA, AN NON-ARTICULATED IMU IS USED. A MULTIDIMENSIONAL TARGET TRAJECTORY ESTIMATOR IS USED TO SPEED UP THE POINTING CONTROL LOOPS. SYSTEM PARAMETERS MAY CHANGE WITH TIME AND THE SERVOSYSTEM CAN BECOME NONLINEAR DUE TO MANY FACTORS (E.G., FORCE COIL VOLTAGE APPROACHING SUPPLY BUSS VOLTAGE). THEREFORE THE SERVOCONTROL MEASURES SYSTEM PARAMETERS ON-LINE WITH AN IMPEDANCE CHARACTERIZER TO PREDICT NONLINEARITIES BEFORE THEY ARE ENCOUNTERED.

GENERIC POINTING MOUNT



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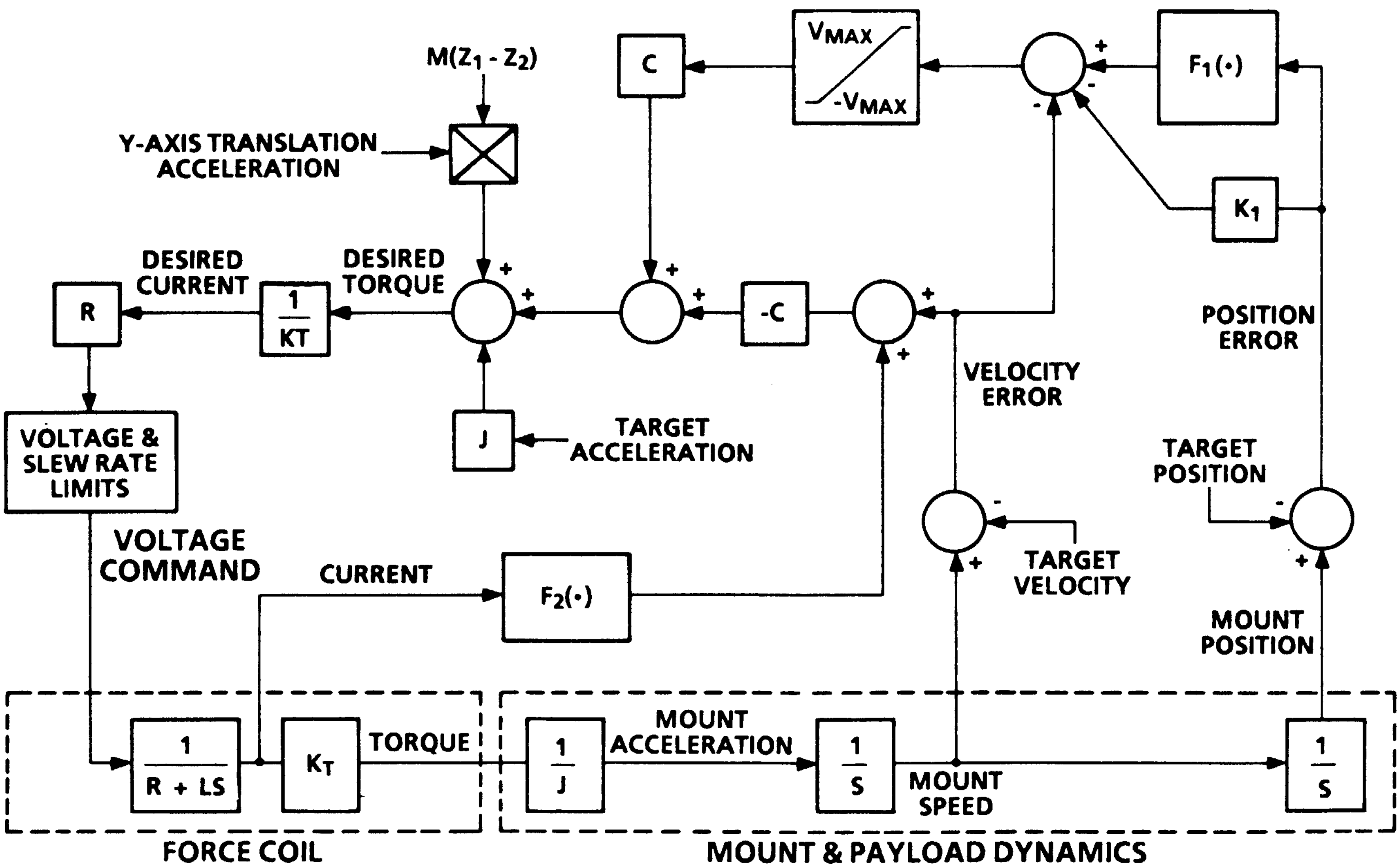
GENERIC POINTING MOUNT

THE GENERIC POINTING MOUNT USES A SPHERICAL MAGNETIC FORCE/TORQUE GENERATOR TO APPLY TORQUES IN THREE AXES AND TRANSLATIONAL FORCES IN THREE AXES TO A 10" SPHERE ATTACHED TO A PAYLOAD MOUNTING SURFACE. THE SPHERE CAN ARTICULATE 120 DEGREES IN THE TIP AND TILT AXES AND CAN ROTATE WITHOUT LIMIT IN THE ROLL AXIS. BY MOUNTING THE PAYLOAD AT A 60 DEGREE ANGLE RELATIVE TO THE MOUNT AXIS, ROLLING THE PAYLOAD CAN ALLOW IT TO "LOOK OVER THE HORIZON" AND THUS OBTAIN AN EFFECTIVE 240 DEGREE OF TIP AND TILT ARTICULATION. RING LASER GYROSCOPES AND ACCELEROMETERS ARE USED BY BOTH IMU'S. POWER IS TRANSMITTED ACROSS THE MAGNETIC SUSPENSION GAP BY MICROWAVES. COMMANDS AND DATA ARE TRANSMITTED ACROSS THE GAP BY OPTICAL LINK ARRAYS. AUTO COLLIMATORS ARE USED TO CALIBRATE THE IMU'S. THE DESIGN IS SCALABLE FOR LARGER SIZE PAYLOADS.

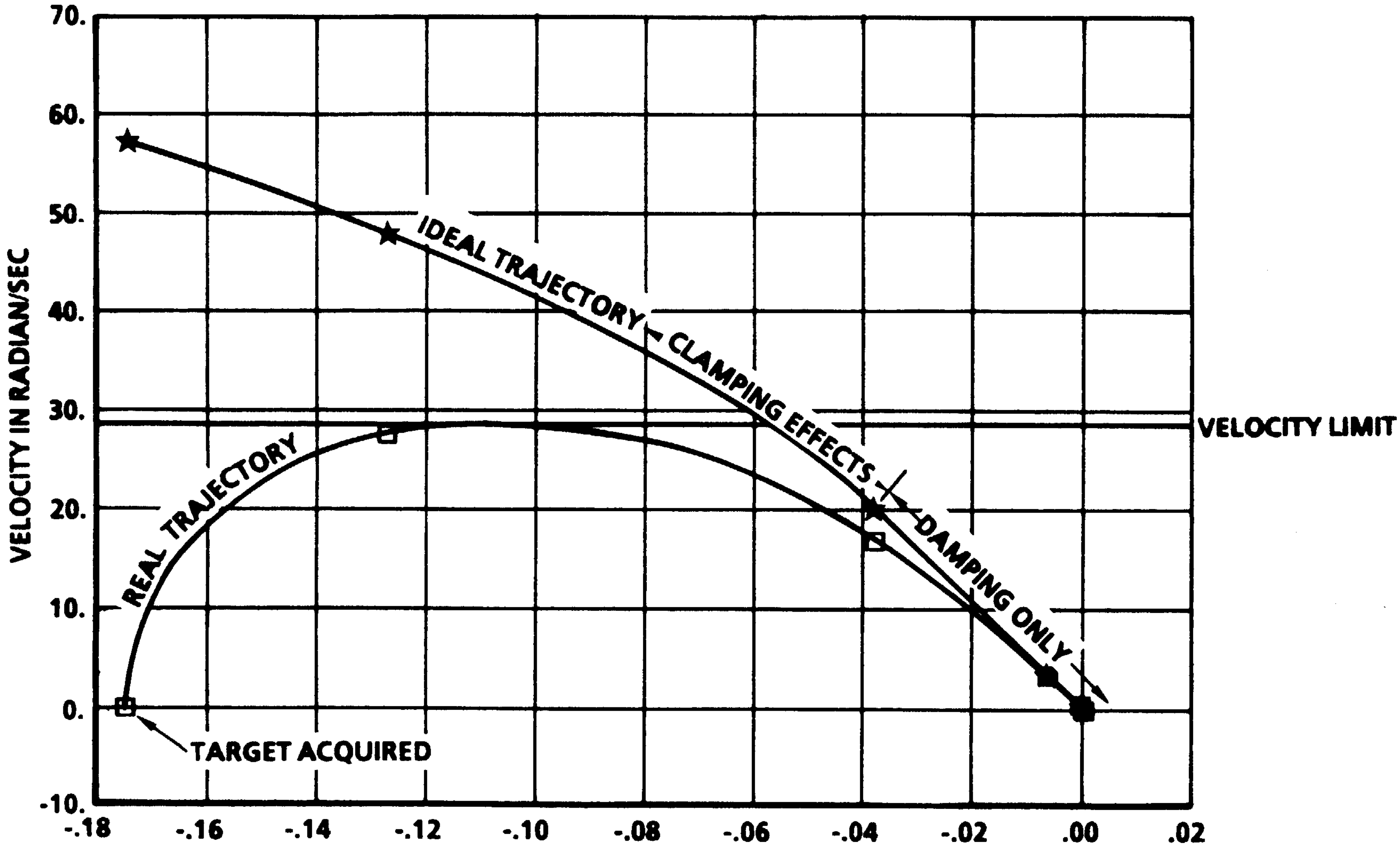
TIP AXIS ROTATIONAL CONTROL AND PLANT BLOCK DIAGRAM



TIP AXIS ROTATIONAL CONTROL AND PLANT BLOCK DIAGRAM

CONVENTIONAL MAGNETIC SUSPENSIONS CAN BE CHARACTERIZED AS MASS-SPRING-DAMPING RESONANT SERVOSYSTEMS WHERE THE MASS IS PRIMARILY DUE TO THE PHYSICAL INERTIA OF THE SUSPEND OBJECT, AND THE SPRING AND DAMPING ARE ESTABLISHED BY THE SERVOSYSTEMS SENSORS, CIRCUITRY AND MAGNETIC FORCE GENERATORS. THE SERVOSYSTEM DAMPING CAN USUALLY BE EFFECTIVELY ACHIEVED ONLY OVER A LIMITED FREQUENCY RANGE IF VELOCITY IS DERIVED BY DIFFERENTIATION. IN CONTRAST, THE GENERIC POINTING MOUNT CAN BE CHARACTERIZED AS A MASS-DAMPING SYSTEM WITH NO "CLASSICAL" SPRING. AN IDEAL VELOCITY ERROR IS CONTINUOUSLY DETERMINED AND SET AS A SERVOSYSTEM OBJECTIVE FUNCTION TO ASSURE THAT ZERO ERROR FOR POSITION VELOCITY, ACCELERATION, AND JERK CAN BE ACHIEVED SIMULTANEOUSLY. THIS ASSURES MINIMUM SETTLING TIME. THE CALCULATION OF THE IDEAL VELOCITY HAS TO ACCOUNT FOR CLAMPS AND NONLINEARITIES (E.G., LIMITED BUSS VOLTAGE, VELOCITY LIMITS ON GYROSCOPES, ETC.) THAT WILL BE ENCOUNTERED DURING THE ENTIRE (FUTURE) PERIOD. THE SERVOSYSTEM APPLIES TORQUES AND FORCES TO PREVENT POINTING ERRORS DUE TO FUTURE OFF-AXIS DISTURBANCES. THIS IS PRIMARILY DUE TO NON-SYMMETRIES BETWEEN THE INERTIAS IN THE VARIOUS PAYLOAD AXES.

VELOCITY TRAJECTORY PLANNER



☆ IDEAL VELOCITY ERROR TRAJECTORY ☐ VELOCITY ERROR

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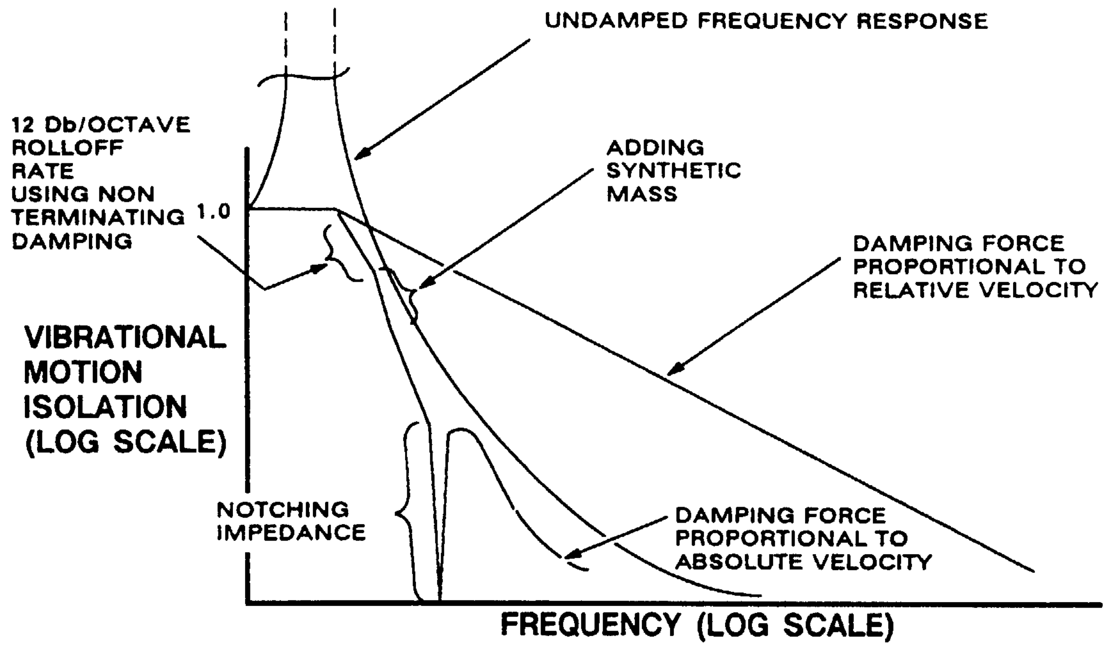
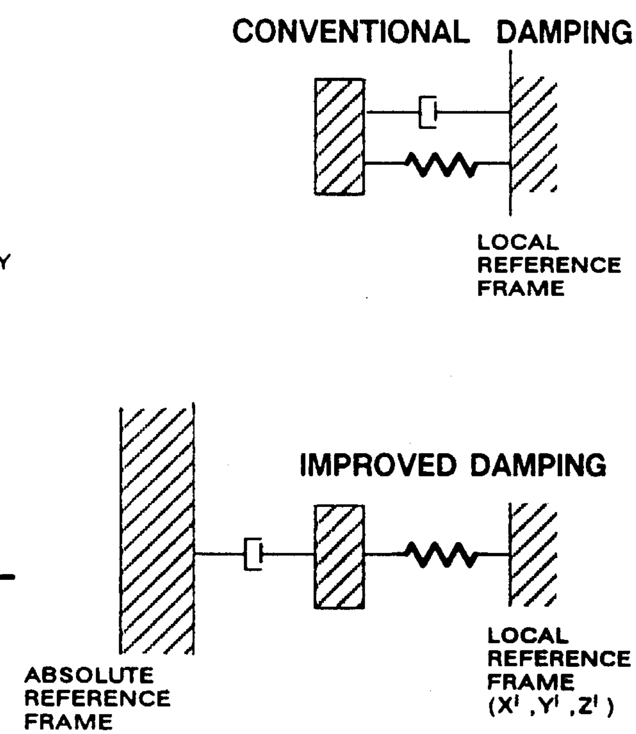
VELOCITY TRAJECTORY PLANNER

AT ANY GIVEN TIME, THE POINTING MOUNT AND PAYLOAD WILL HAVE MULTIPLE POINTING ERRORS (POSITION, VELOCITY, ACCELERATION, JERK, VOLTAGE/CURRENT/FREQUENCY) IN BOTH THE TIP AND TILT AXIS. SIMILAR ERRORS WILL ALSO EXIST IN THE ROLL AND THREE TRANSLATIONAL AXES. IT IS DESIRABLE TO REDUCE ALL OF THESE ERRORS TO ZERO AT THE SAME TIME AND AS QUICKLY AS POSSIBLE WITHOUT OSCILLATIONS. FOR A MASS-DAMPING SYSTEM THERE IS AN IDEAL RATIO OF VELOCITY ERROR TO POSITION ERROR THAT WILL ZERO OUT ALL ERRORS AT THE SAME TIME. THIS RATIO IS A FUNCTION OF THE INERTIA AND THE DAMPING CONSTANT. IF POSITION ERRORS ARE SMALL, THE SERVOSYSTEM CAN OPERATE LINEARLY AND THE IDEAL VELOCITY ERROR WILL BE PROPORTIONAL TO THE POSITION ERROR BUT WITH OPPOSITE SIGN. IF POSITION ERRORS ARE LARGE, MANY NONLINEARITIES (E.G., VELOCITY OR VOLTAGE CLAMPS) CAN CAUSE THE IDEAL VELOCITY ERROR TO BE A NONLINEAR FUNCTION OF POSITION ERROR. IF THE IDEAL VELOCITY IS EXCEEDED, OVERSHOOT WILL OCCUR IN POSITION ERROR. IF THE VELOCITY PROFILE IS WELL BELOW THE IDEAL TRAJECTORY, IT WILL CAUSE EXCESSIVE SETTLING TIMES.

IMPROVED VIBRATION ISOLATION AND DAMPING





IMPROVEMENTS AVALABLE:

- NOTCHED IMPEDANCE
- ANTI-NODAL DAMPING FOR ILL MODES
- ORTHOGONAL MODAL DAMPING
- INERTIAL MASS ENHANCEMENT
- FORCE REFLECTION

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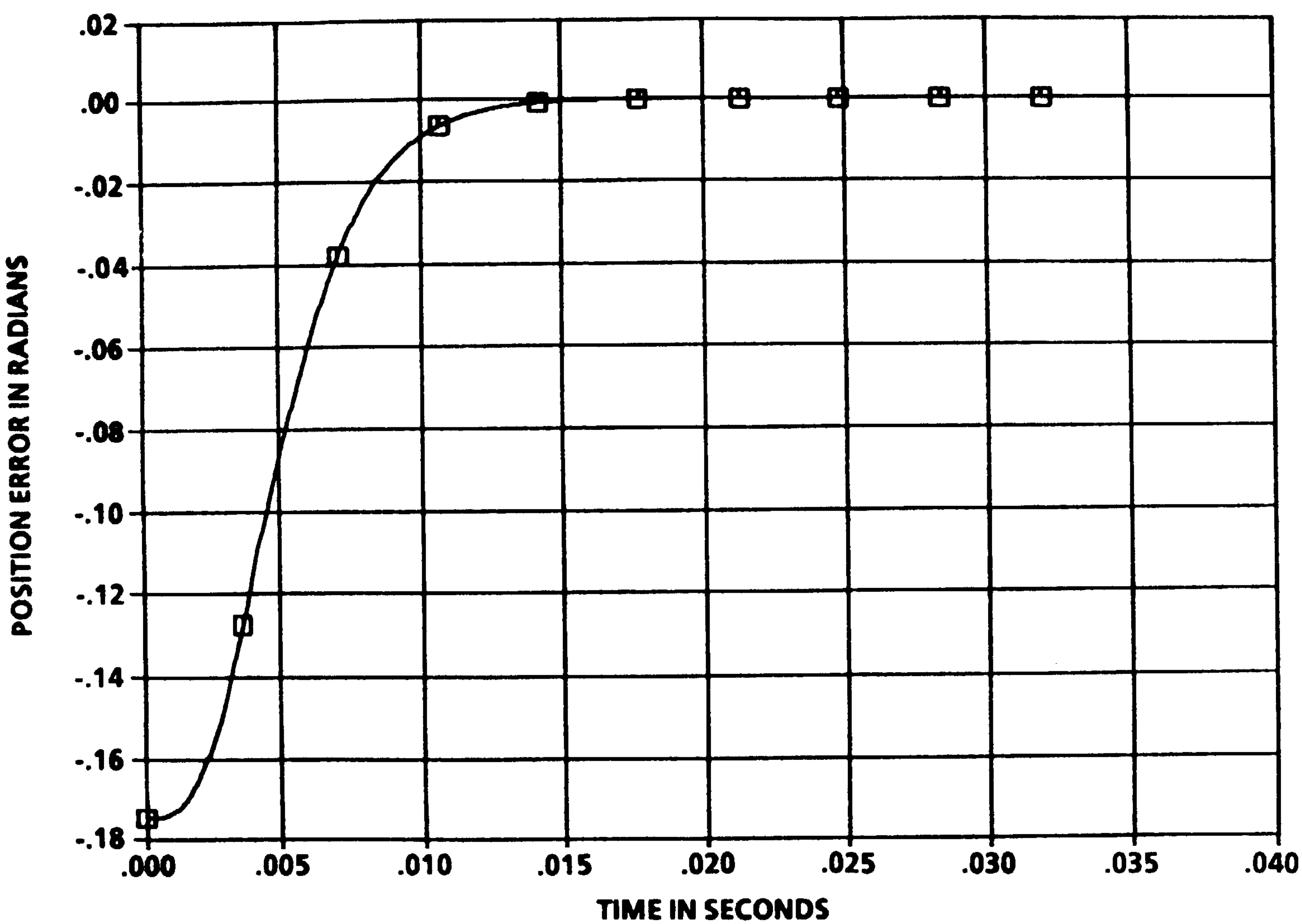
IMPROVED VIBRATION ISOLATION AND DAMPING

MANY ADVANCED TECHNOLOGIES ARE AVAILABLE TO ISOLATE VIBRATION AND DAMP RESONANCES WITH MAGNETIC SUSPENSIONS. THESE INCLUDE:

- NOTCHING THE SUSPENSION IMPEDANCE TO ZERO AT THE FREQUENCIES OF KNOWN RESONANCES.
- DAMPING FLEXURAL CRITICALS SO AS TO SIMULATE ANTINODAL DAMPING REGARDLESS OF MODE SHAPE.
- CONTROLLING THE SUSPENSION IMPEDANCES TOTALLY INDEPENDENTLY FOR EACH RESONANCE. THIS CANNOT BE ACHIEVED WITH SINGLE POINT IMPEDANCE SUSPENSIONS.
- ENHANCE THE "APPARENT" INERTIAL MASS FOR SUSPENDED OBJECTS BY APPLYING MAGNETIC FORCES PROPORTIONAL TO ACCELERATION.
- REFLECT VIBRATIONAL FORCES THAT PASS THROUGH A SUSPENSION BACK TO THE SOURCE.
- INCREASE ROLL OFF RATE OF SUSPENSION ISOLATION VERSUS FREQUENCY BY USING INERTIALLY REFERENCED VELOCITY RATHER THAN RELATIVE VELOCITY FOR DAMPING.

POSITION RESPONSE NOMINAL CONDITIONS WITH TRAJECTORY PLANNER & LIMITERS



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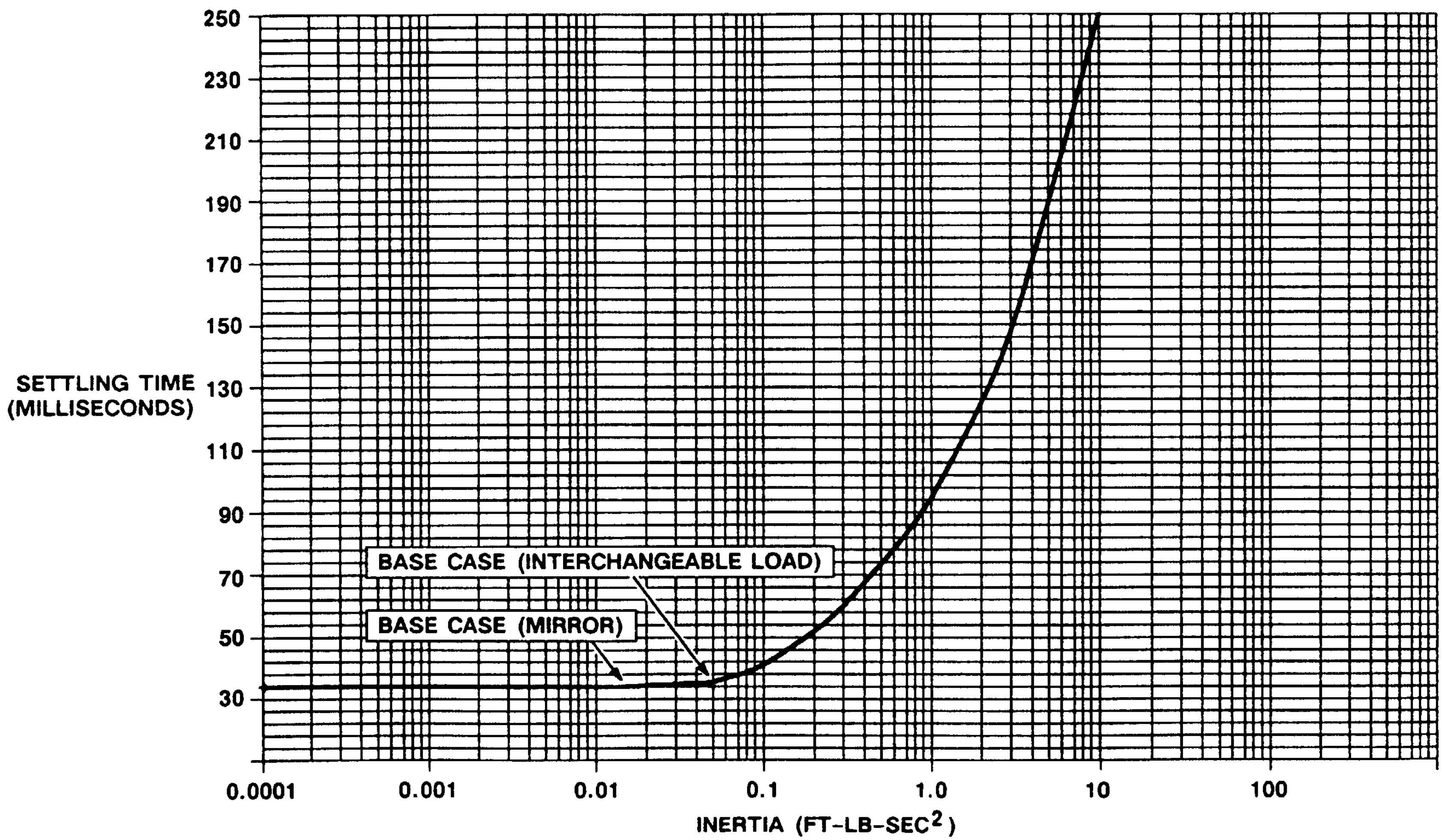
POSITION RESPONSE NOMINAL CONDITIONS WITH
TRAJECTORY PLANNER & LIMITERS

THE GENERIC POINTING MOUNT CAN REDUCE POINTING ERRORS BY SIX ORDERS OF MAGNITUDE IN LESS THAN 35 MILLISECONDS IF PRECISE AND ACCURATE SENSORS ARE UTILIZED.

SETTLING TIME VERSUS INERTIA



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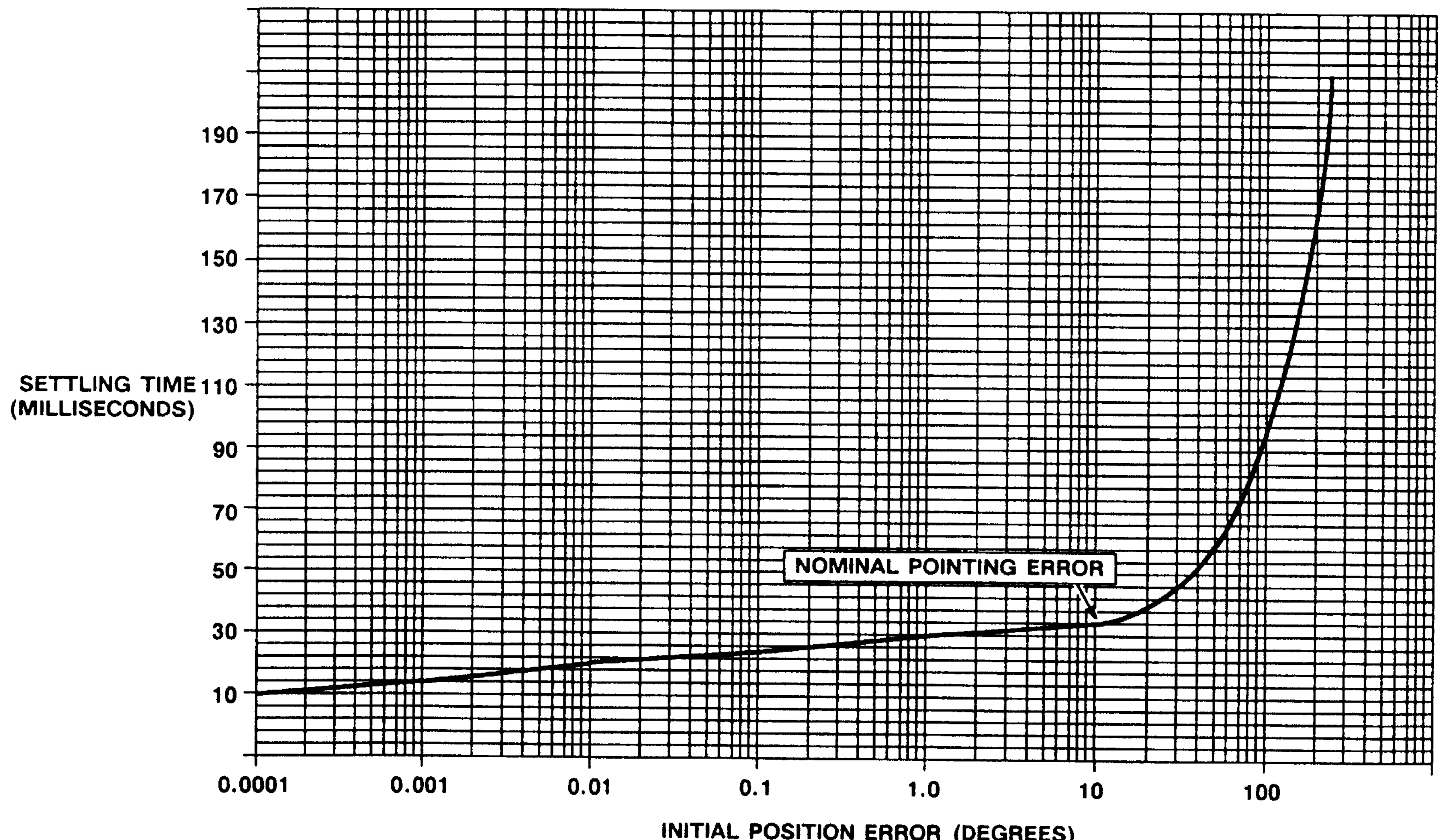
SETTLING TIME VERSUS INERTIA

(FOR AN INITIAL 10 DEGREE POINTING ERROR)

INCREASING PAYLOAD INERTIA DOES NOT INCREASE SETTING TIME (FOR 6 ORDERS OF MAGNITUDE ERROR REDUCTION) UNTIL THE MAGNETIC TORQUE GENERATOR BECOMES SATURATED. THE SETTLING INCREASES NON-LINEARITY BEYOND THIS POINT

SETTLING TIME VERSUS INITIAL POSITION ERROR BASELINE CASE (MIRROR)



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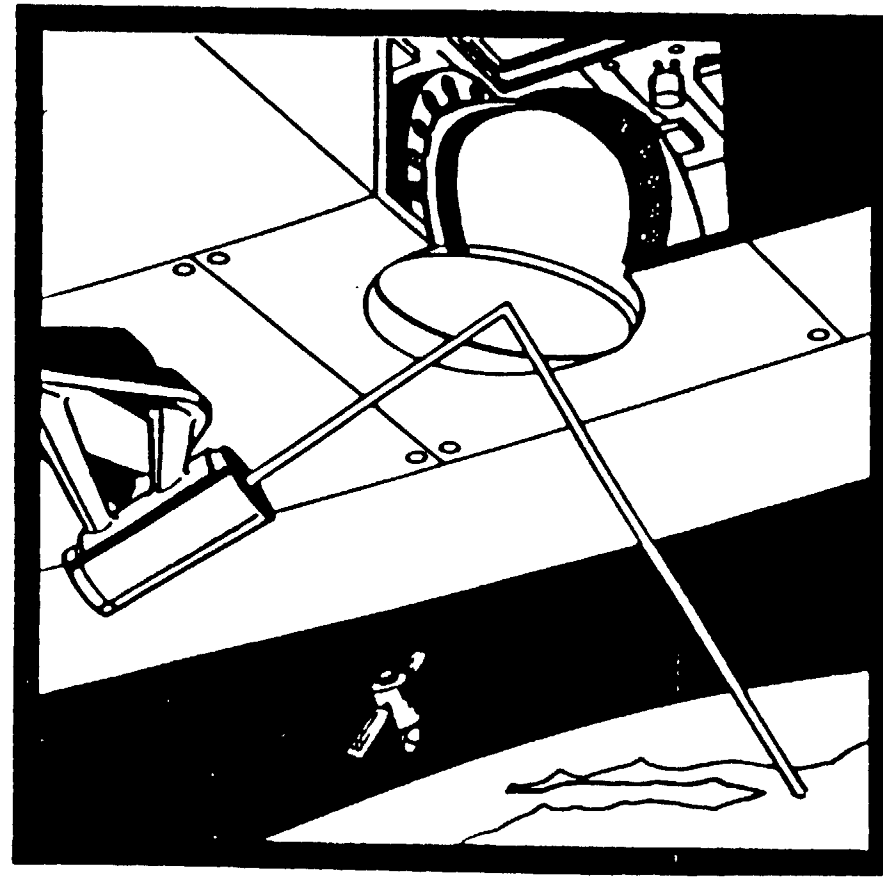
SETTLING TIME VERSUS INITIAL POSITION ERROR
BASELINE CASE (MIRROR)

SETTLING TIME INCREASES ONLY AS A FUNCTION OF THE SQUARE ROOT OF INITIAL POSITION ERROR UNTIL THE MAGNETIC TORQUE GENERATOR IS SATURATED. IT IS NON-LINEAR BEYOND THIS POINT.

SUMMARY OF SYSTEM FEATURES

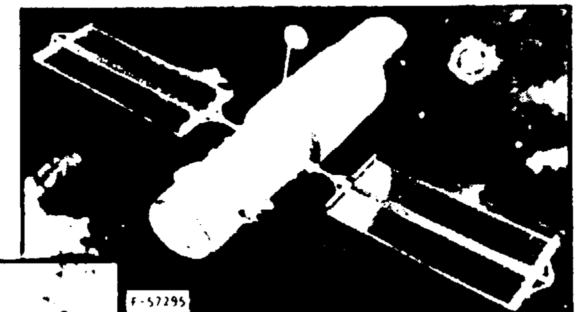
- GENERIC POINTING MOUNT FOR INTERCHANGEABLE PAYLOADS
- SYSTEM AUTOMATICALLY ADAPTS CONTROL LAWS TO EACH PAYLOAD
- POINTING CONTROL IN THREE AXES AROUND A SINGLE PIVOT POINT
- 240-DEG ARTICULATION ANGLES



OTHER APPLICATIONS FOR GENERIC MAGNETIC SUSPENSION TECHNOLOGIES

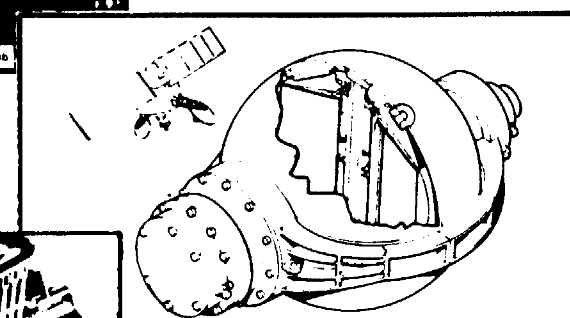
MAGNETIC SUSPENSIONS PROVIDE IMPROVED:

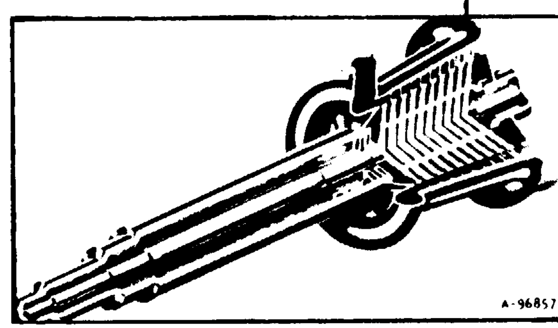
- ISOLATION AND POINTING
- VIBRATION CANCELLATION
- BEARINGS



SPACE TELESCOPES

SUBMARINES


SHORT ROTORS



LONG ROTORS

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