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Scaling the Electromagnetically Driven Explosive Shock Simulator

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A heavy payload electromagnetically driven explosive shock simulator, referred to as EDESS-3, has been assembled and characterized at the Naval Surface Weapons Center. EDESS-3 is the logical outgrowth of the earlier EDESS 1 and 2 simulator work which explored the use of electrical pulse power technology for the generation of explosive like shocks. This paper presents the features of EDESS-3, reviews the shock generation concept, and introduces designs for the next generation of EDESS machines.

INTRODUCTION

EDESS-3 (the third generation of Electromagnetically Driven Explosive Shock Simulator), has been successfully evaluated at the Naval Surface Weapons Center. EDESS-3 has a twenty ton payload and is the culmination of a NAVSEA Program to develop and demonstrate an alternate technology for shock testing equipment to MIL S 901C type shocks over a wider range of payload weights. EDESS technology holds the promise of providing the mechanical designer and equipment qualifier with the means to perform shock developmental and qualification testing in a laboratory setting over the full MIL S 901C range of equipments.

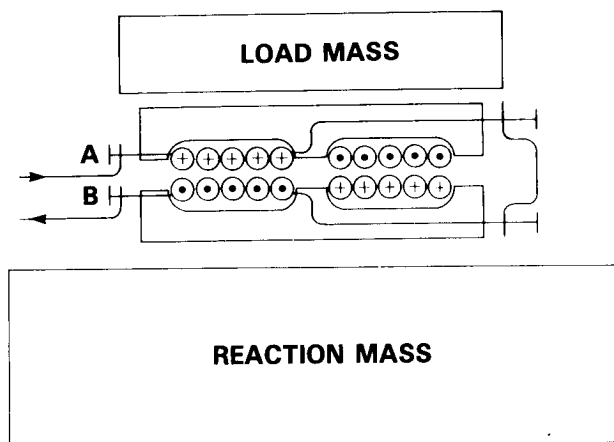
The groundbreaking EDESS 1 and 2 established the engineering practicality of using pulse-power for generating explosive like shocks in significant payloads. The 2 ton payload EDESS-1 and 5 ton EDESS-2 laid the groundwork for many of the techniques integrated into EDESS-3. These earlier machines pioneered the use of pancake drive coils, high energy density capacitor banks, triggered backstrap switching, and air suspension and isolation of the reaction mass.

The shock output of EDESS-3 has been carefully characterized from a large number of acceleration measurements. The resulting shock signatures strongly correlate with floating shock platform signatures for similar loads. Shocks measured in a 20-ton armor plate load at full rated bank energy are routinely in excess of 100 g's with velocities of 11 ft/sec and center of mass displacements of 13 inches.

CONCEPT OF OPERATION

EDESS develops explosive like shocks in subject test objects, as a result of the magnetic repulsive force between pairs of spiral pancake magnetic coils that are positioned between a large reaction mass and the test carriage upon which the test object is mounted. The driving energy is supplied from the electrostatic energy stored in capacitor banks and is transferred to the coil pairs by the closure of a high voltage/high current triggered switch.

The concept is illustrated in Figure 1. The figure shows a cross section of a typical pair of single layered, spirally wound pancake coils connected in series opposition.



When a pulse of current flows from terminals A to B through the spiral paths of the two coils, a large magnetic repulsive force is developed between the coils as a result of the opposite flow through each of the nearly touching circular coils. A (+) refers to current flow into the plane of the drawing; while a (•) refers to flow out of the plane. The series inductance and capacitance can be varied to generate a variety of single shock pulses. The design details are developed in some detail in Reference 2. In general, once the system capacitance is established by the capacitance of the energy storage banks, the time constant and associated rise time of the driving pulse can be defined through the suitable selection of driving coil inductance.

Figure 1. Shock Generation Concept

TECHNICAL DETAILS

EDESS-3 capacitor banks utilize high energy density capacitors which result in net energy densities of 2.78kJ/cu ft, with a system capacity of 1.5MJ. The banks are assembled with 20 each 125ufd, 20kVDC capacitors; Maxwell Laboratories, Inc. part No. 32289. Each of the three resulting 500kJ energy storage banks in the current system is a forklift manageable, modular steel construction weighing approximately three tons and occupying 108 cu ft. Reference is made to Figures 2 and 3. Figure 2 shows the internal details of the standard 500kJ bank. The schematic of Figure 3 outlines the electrical details of the EDESS-3 machine. For internal protection the banks utilize series current limiting resistors and protective fuses. Referring to Figure 3, the current limiting resistors (1) limit the discharge current that the individual capacitors (2) can achieve in case of a shorted load. The protective fuses (3) are specified to prevent destructive discharge of the entire bank or banks into a shorted capacitor. The twenty parallel capacitors feed a low inductance triaxial transmission line (4), designed to minimize the bank time constant and rise time. Each bank contains integral charge current limiting resistors and protective fuses (5), dump resistor networks (6) and associated remote controlled contactors (7), for the charge disconnect and

dump modes of operation. The triaxial feed lines join at the forward end of the banks where they are serviced by a single triggered switch.

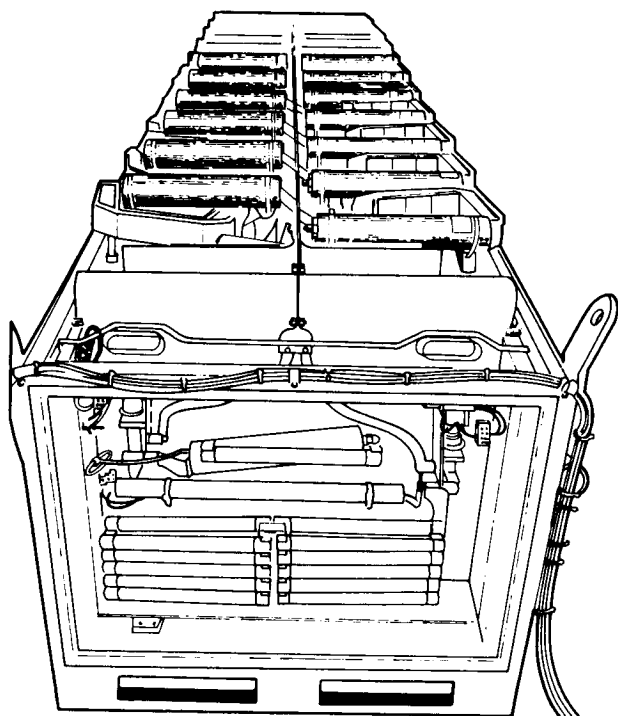


Figure 2. 500 kJ Capacitor Bank

peak shocks. To this end, the switch has undergone an evolutionary process culminating in the current radial trigger pin configuration which offers reliable triggering over the entire useful EDESS charge voltage range. The radial trigger pin, which supplanted the earlier coaxial pin design, is triggered by the discharge of a five stage, 100kV marx type high voltage trigger generator. This combination of radial trigger pin and high trigger voltage allows wide main switch gapping with consistent triggering which is generally independent of the capacitor bank's charge voltage.

The switch electrodes are machined graphite cylinders of four-inch diameter and six-inch length. The discharge end of each electrode is hemispherically shaped to minimize any pre-fire enhancing sharp geometries. Earlier switch designs demonstrated self-destructive tendencies due to plasma growth associated

Switching of the electrical energy is accomplished through a pin triggered backstrap type high voltage/current switch, utilizing canted graphite electrodes which operate in a plasma quenching atmosphere. The switch design has emphasized long life/low maintenance electrodes with a wide, no adjustment, operating voltage range. The EDESS machine is designed to offer the user wide latitude and ease of selection of

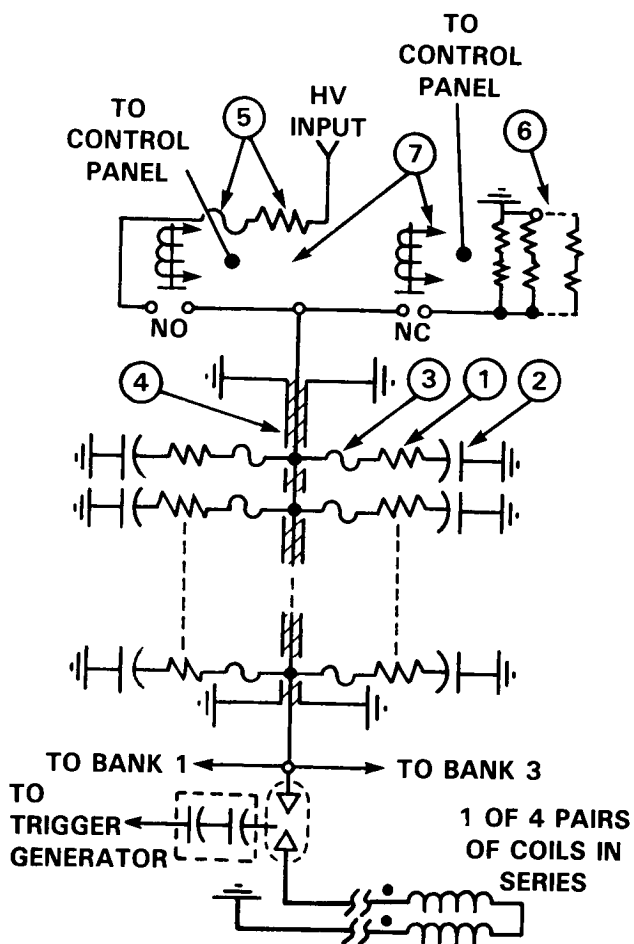


Figure 3. EDESS-3 Electrical

with the switch geometry and backstrap displacement of the plasma. To overcome this, the EDESS-3 switch utilizes a canted geometry and a plasma quenching sulfur hexafluoride operating atmosphere which reduces electrode and mounting bracket damage. The resulting switching arrangement shown mechanically in Figure 4 has demonstrated a life to date in excess of several hundred shots with no damage and minimal maintenance. Operationally the switch features dependable, no adjustment, triggering over the entire usable operating range of the simulator.

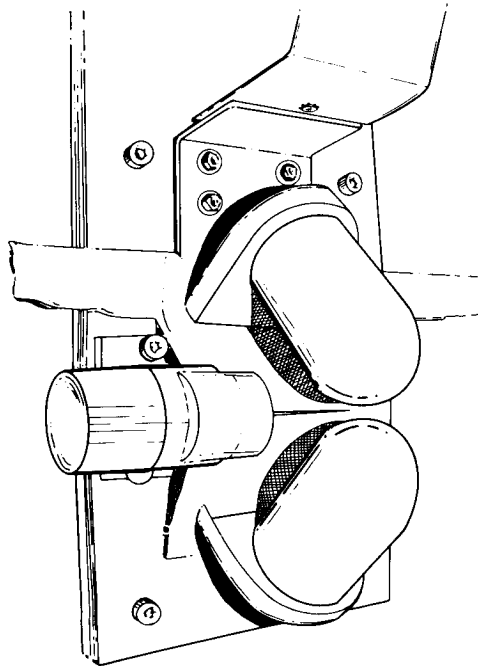


Figure 4. Triggered Backstrap Output Switch

The mechanical design of EDESS-3 depicted in Figure 5, utilizes twelve air springs (1) to effectively shock isolate the reaction mass from the concrete laboratory floor. The reaction mass (2) consists of 80 tons of steel armor plate and provides a four to one mass ratio with the maximum capacity of the machine. The test carriage (3), a 20 ton armor plate in the current machine is supported on four bi-directional hydraulic cylinders. The cylinders in combination with accumulators and one-way bypass valves (4) (and shown in detail in Figure 6) form a passive load catcher system, which serves the dual purpose of preventing rebound

shock to the coil pairs and elimination of rebound shock to the test object. The hydraulics in conjunction with the four guide pins (5), maintain the alignment between the test carriage and the reaction mass, thereby insuring the maximum force between the coil pairs. EDESS-3 utilizes four driving coil pairs, Figure 7, the coils being of the single layer spiral wound design, that has been established in earlier simulators. The four pairs of 30 inch diameter coils, backed with G-10 fiberglass forms, are veterans of over 300 shock shots and have demonstrated only superficial wear.

OPERATIONAL RESULTS

Subsequent to developmental testing, a characterization test series was performed to highlight shock performance as a function of operating voltage and spacial parameters. The EDESS was tested at charge voltages of 10-20kV which translates to 25-100 percent of the stored energy capacity of the 1.5MJ capacitor banks. For the purpose of these tests the machine was loaded with a twenty ton armor plate. Operational shock data was acquired from two accelerometer arrays, each utilizing five ENDEVCO model no. 2262-2000 accelerometers. The first array mapped corner-to-corner variations, while the second highlighted variations along a typical diagonal. The location of the accelerometer arrays is shown in Figure 5.

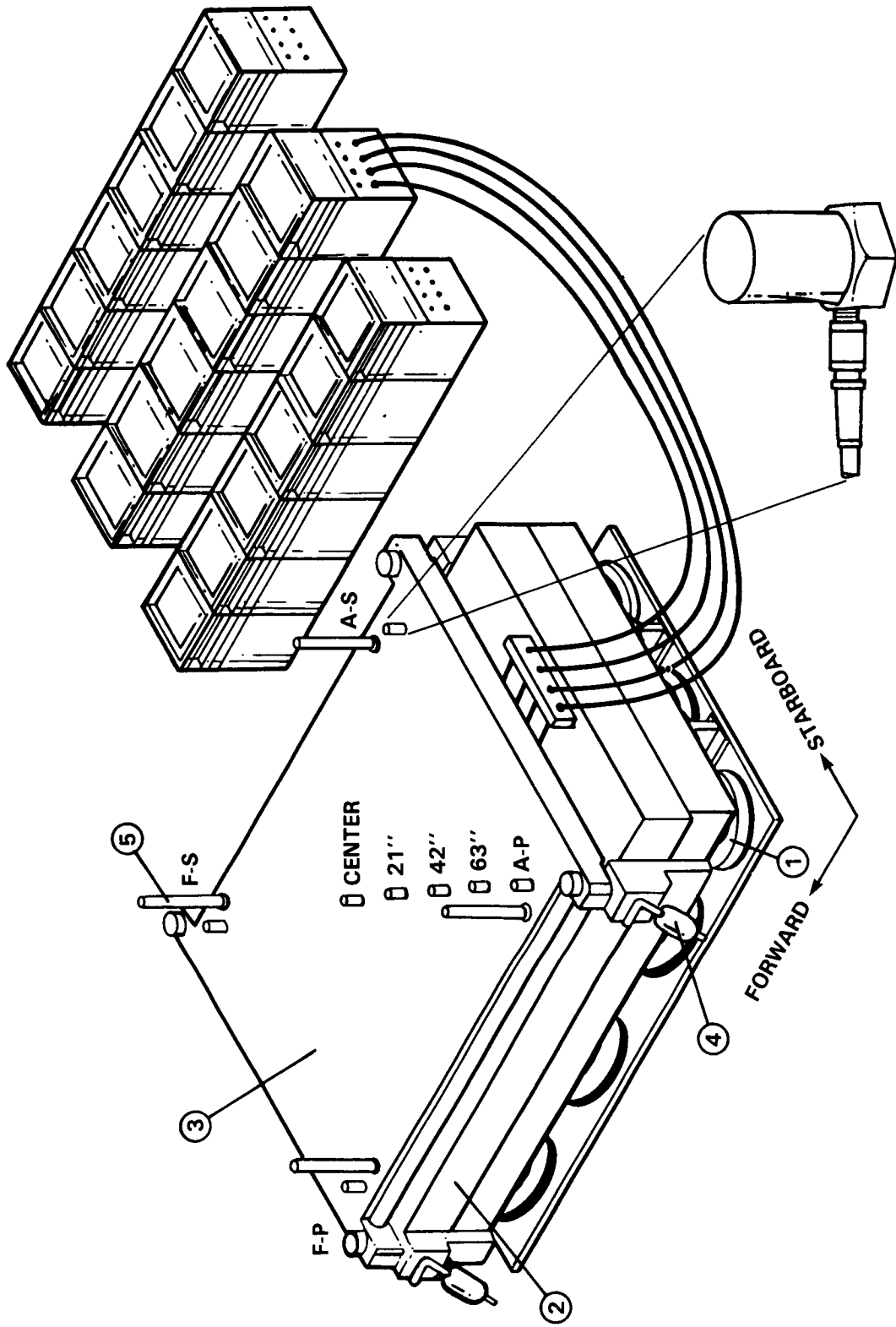


Figure 5. EDESS-3

Figure 8 reproduces a typical shot data sheet reduced from data acquired during the characterization test series. This particular example is of a 20kV (100 percent energy) shot with measurements from the accelerometer located at the center of the test mass. The upper left trace shows measured acceleration in g's which has been low pass filtered with a cutoff frequency of 2kHz. The second trace is of digitally integrated acceleration - velocity in ft/sec. The third left trace is of 200 Hz filtered acceleration data, while the second integral or displacement is shown at bottom left in units of inches. For each of these plots the time base is in units of seconds. At upper right, a pictorial view of the test mass locates the accelerometer from above. The lower right shock spectrum is plotted on a four-coordinate system with frequency on the abscissa and spectral acceleration on the ordinate.

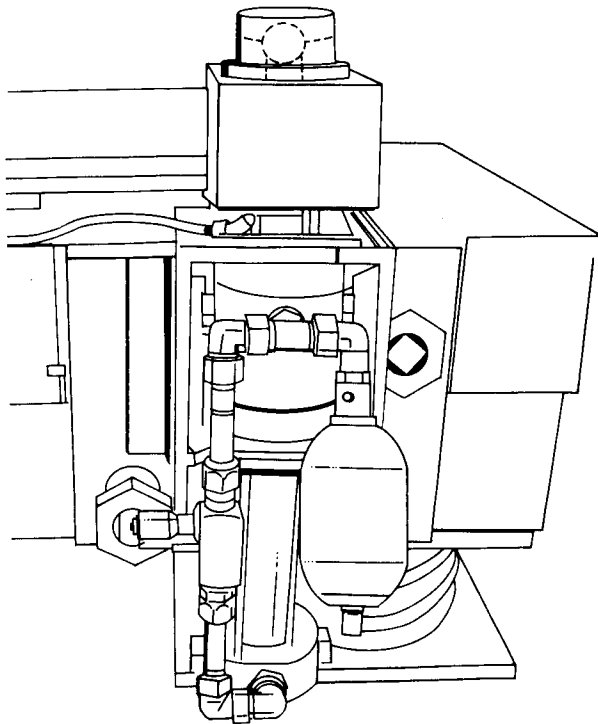


Figure 6. Hydraulic Load Catcher System

Tables 1 and 2 give summarized acceleration and velocity data respectively versus position on the test load and operating voltage of the simulator. Figures 9a-d present the data of Tables 1 and 2 in a graphical form.

FUTURE WORK

NSWC has developed designs for EDESS type machines capable of producing multi-axis shocks such as the vertical and athwartship motion, associated with underwater explosion (UNDEX). A preliminary

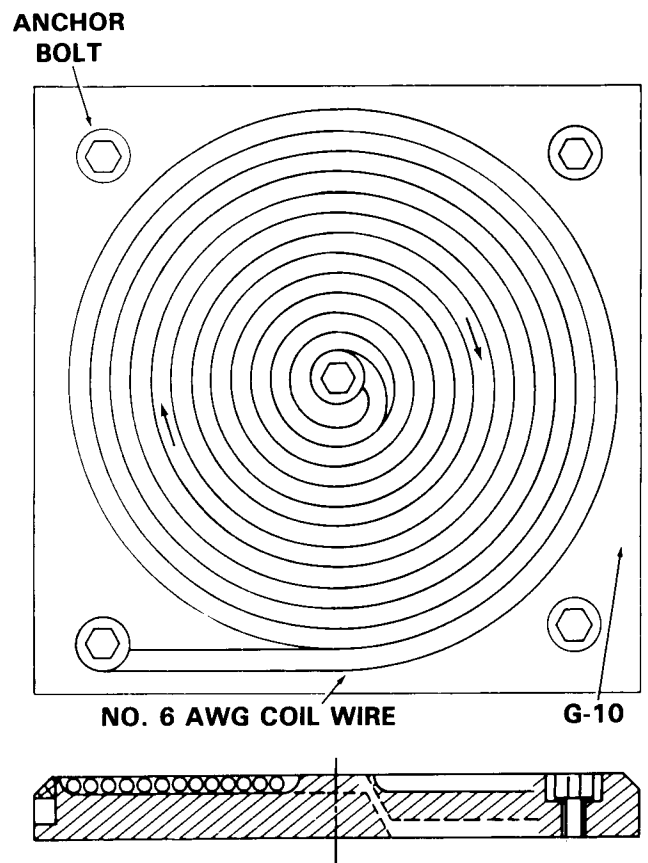
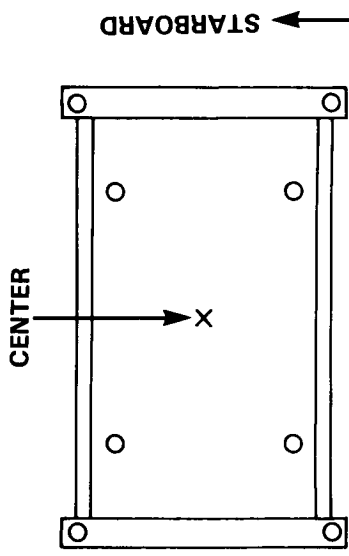
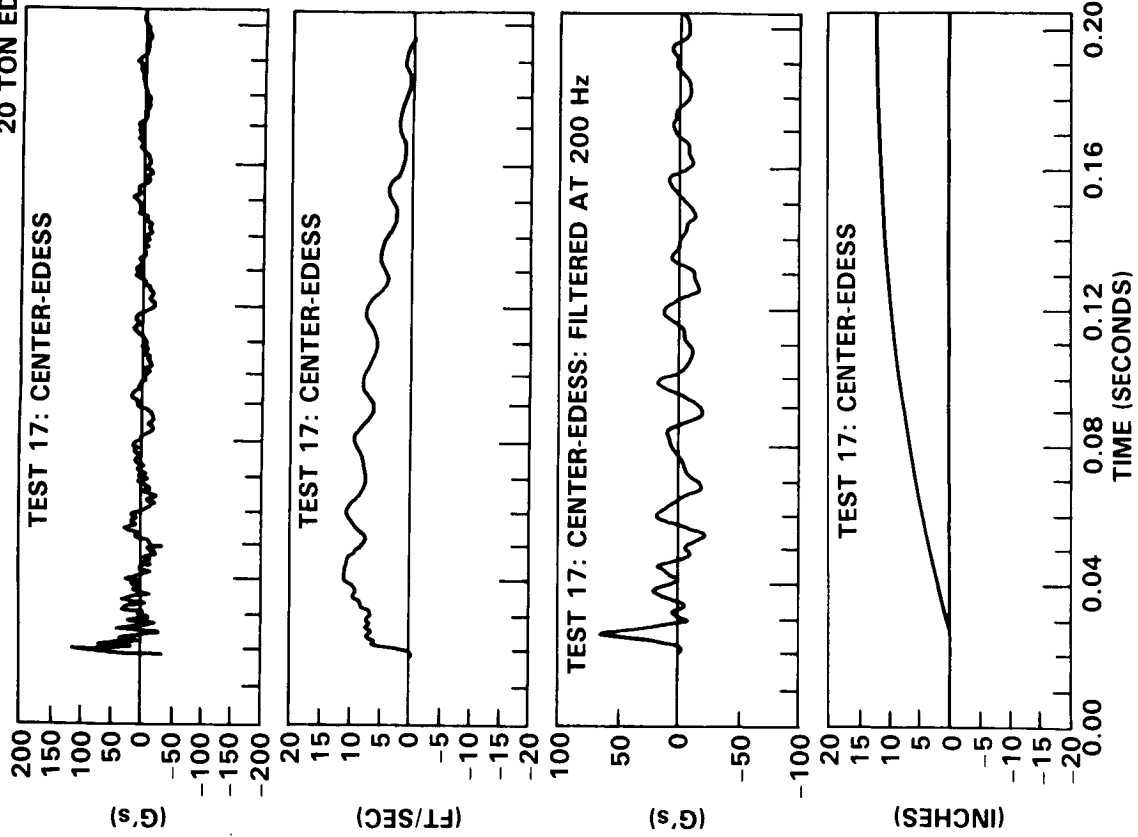


Figure 7. Pancake Drive Coils

20 TON EDESS - 20 kV



TEST 17: CENTER-EDESS: SHOCK SPECTRUM AT ZETA = 0.020 DISPLACEMENT (INCHES)

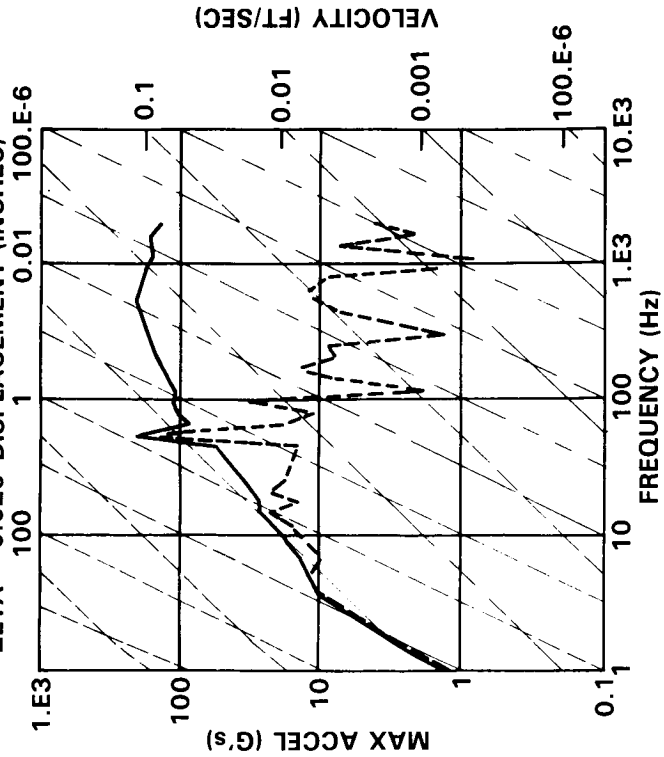


Figure 8. 20KV Characterization Data

ACCELERATION¹ g's-FOR VARIOUS LOCATIONS²

OPERATING VOLTAGE (KV)	AP	FP	FS	AS	C	21"	42"	63"
10	13.9	13.0	12.6	13.4	18.4	20.8	14.3	11.6
12	18.1	18.0	17.6	18.1	26.1	27.9	19.0	15.0
14	24.0	25.0	24.4	26.4	35.8	37.0	25.0	19.9
16	30.4	31.1	32.0	31.7	45.3	46.1	31.1	25.2
18	38.0	37.0	34.0	38.0	56.0	54.7	36.1	28.4
20	44.2				65.0	66.5	44.6	34.0

1. Peak measured acceleration filtered at 200 Hz
2. Accelerometer locations are shown in Figure 5

Table 1. Peak acceleration versus position and operating voltage

VELOCITY¹ FT/SEC-FOR VARIOUS LOCATIONS²

OPERATING VOLTAGE (KV)	AP	FP	FS	AS	C	21"	42"	63"
10	3.6	3.1	3.1	3.2	2.9	3.3	3.1	3.0
12	4.7	4.5	4.5	4.1	4.2	4.7	4.3	4.0
14	7.0	6.5	6.6	5.9	5.5	6.3	5.8	5.5
16	8.7	8.0	9.8	7.8	7.5	8.2	7.7	7.3
18	10.7	10.1	10.4	9.9	9.1	10.1	9.2	8.8
	13.1				11.0	12.4	11.2	10.8

1. Peak calculated velocity
2. Accelerometer location from which velocities are calculated is shown in Figure 5.

Table 2. Peak velocity versus position and operating voltage

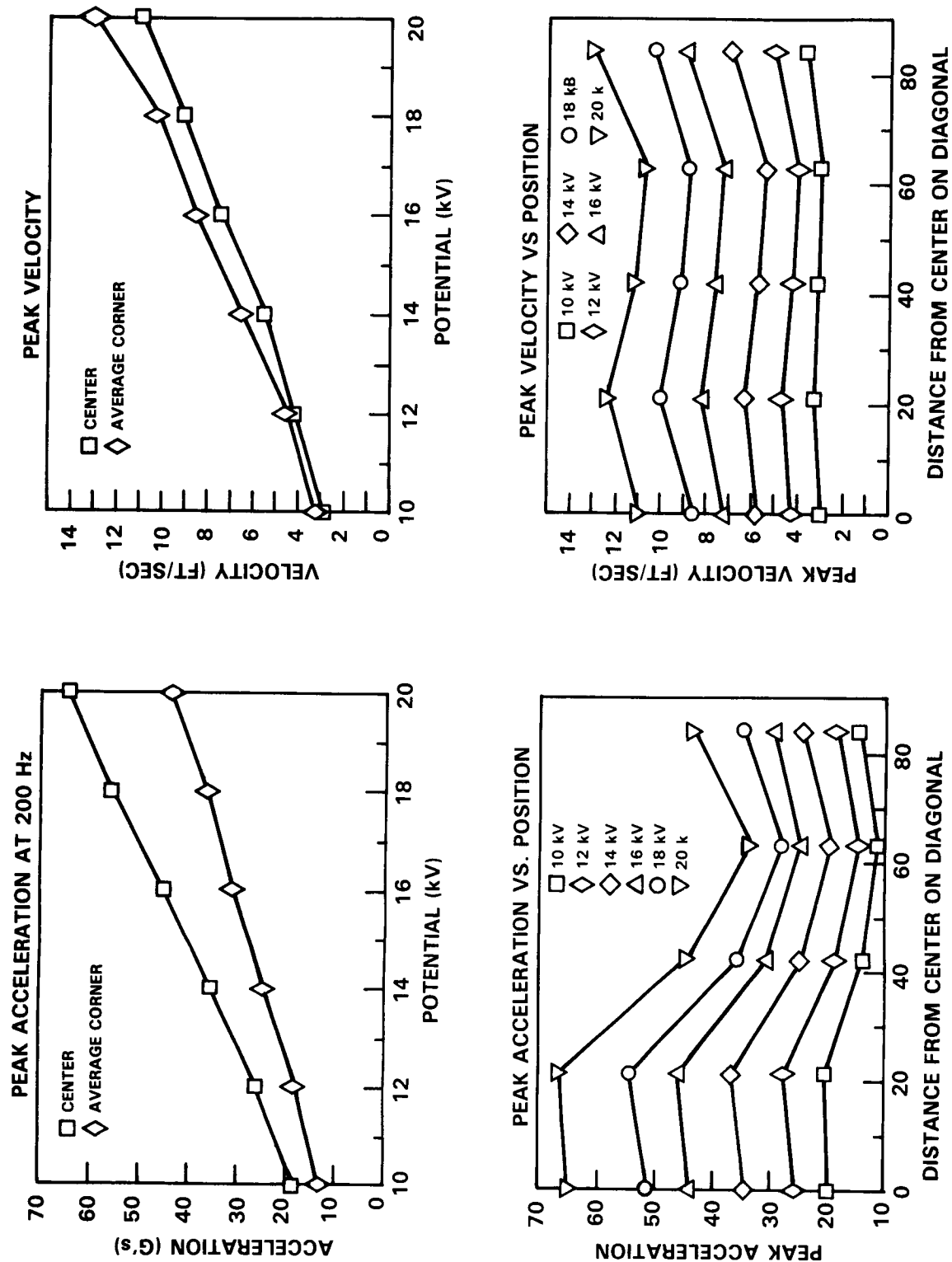


Figure 9. Acceleration and Velocity Data Summaries

design for an EDESS configured to simulate air blast induced shock (ABIS) has been proposed, as have designs for vertical axis machines with significantly larger payloads. The multi-axis UNDEX design incorporates EDESS-3 in conjunction with the additional electrical and mechanical components needed to generate as much as 30 percent athwartship motion. Figure 10 shows such a simulator, utilizing two additional coil pairs, horizontal bracing and hydraulic load control components.

Figure 11 is a preliminary design for an ABIS EDESS. This design uses a novel rolling reaction mass in lieu of a large reinforced buttress to absorb the horizontal motion. The ABIS machine translates the horizontal reaction force into rolling motion which is absorbed by a conventional braking system. This design makes use of solenoidal type coil to achieve the somewhat longer duration, lower peak shock associated with ABIS. The test carriage allows simulated deck and bulkhead mounting of a full range of subject equipments. This five ton capacity machine is capable of testing a large majority of the equipments that will be subjected to the ABIS phenomena.

CONCLUSIONS

EDESS-3 has demonstrated the up-size scaling of the smaller EDESS 1 and 2. The perfection of mechanical and electrical techniques, in conjunction with the application of higher energy density capacitors, readily suggest the development of larger and/or multi-axis EDESS machines. With payload capacities and shock simulations equaling or exceeding current shock test capabilities, along with the benefits of testing in a laboratory setting unaffected by inclement weather, the EDESS can make a major contribution towards the goal of shock hardening and qualification.

The success achieved with EDESS-3 strongly encourages future development of these programs and the verification and acceptance of the simulators as shock testing standards.

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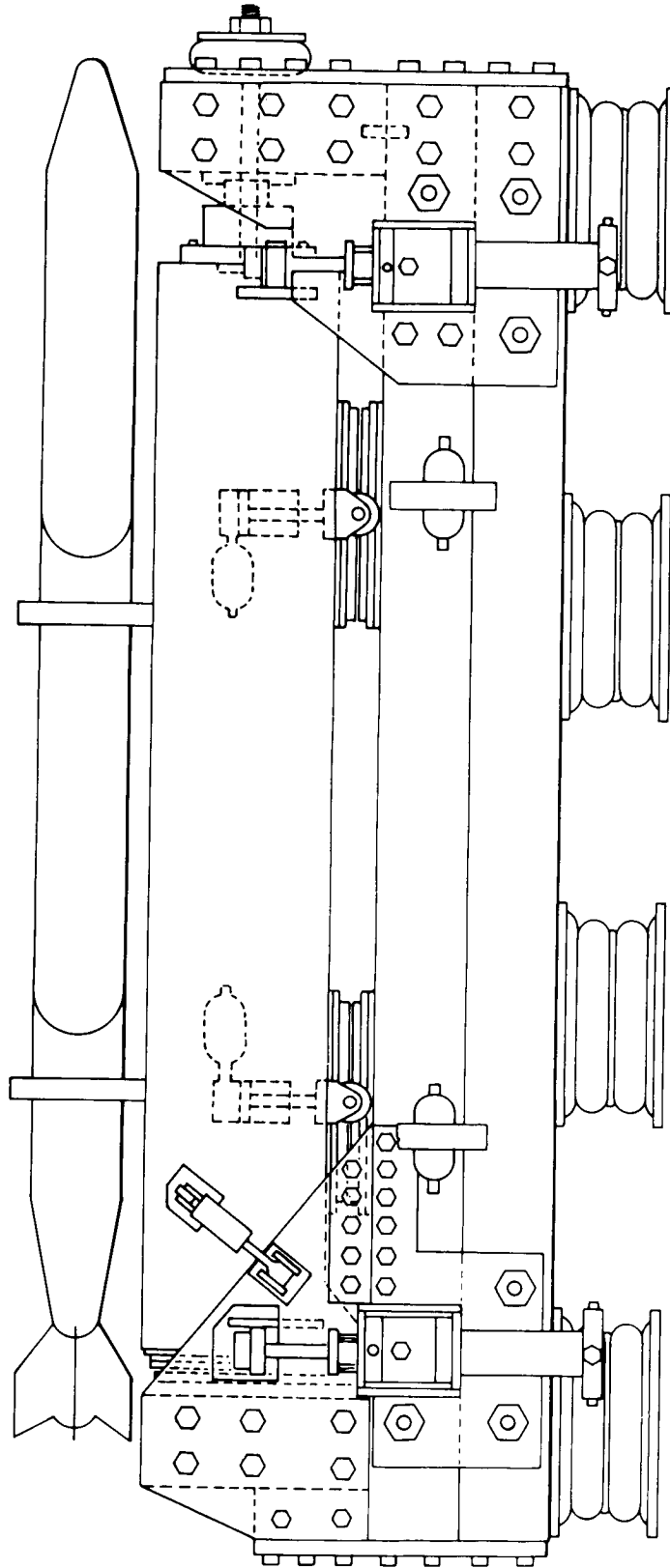


Figure 10. Multi-axis UNDEX EDESS

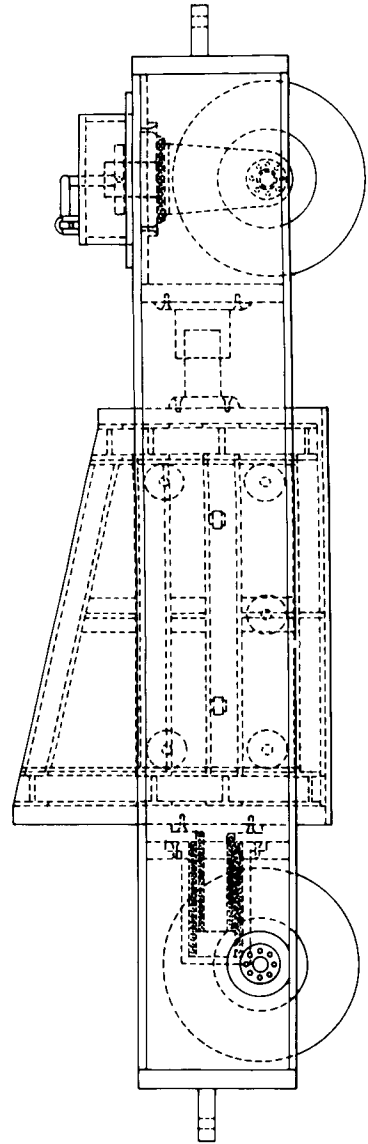
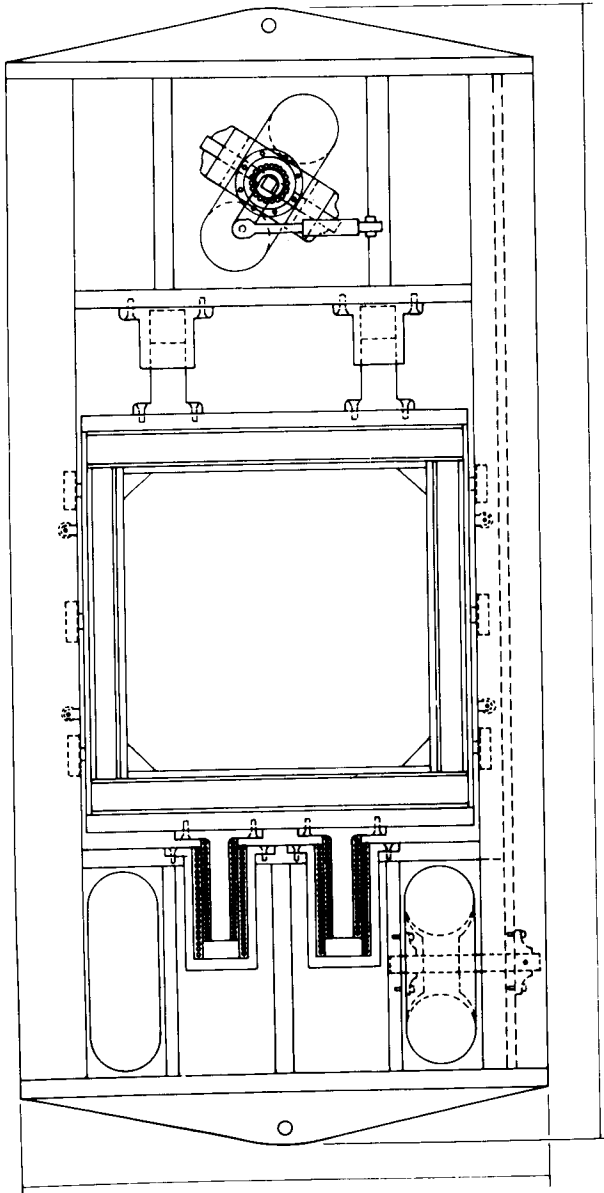


Figure 11. ABIS EDESS