Application of Hydroviscous Drives to Movable Bridges

by

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presented at the

Movable Bridge Symposium

November 4, 1985

Tallahassee, Florida

INTRODUCTION

This paper will describe hydroviscous drives (HVD) and their application to movable bridges.

Industrial HVD's were introduced in the early 1960's, but their application to movable bridges is relatively new. Most industrial HVD applications have been in the "P2M2" area, namely, Powerplants, Petrochemical plants, Mining and Marine.

Here, thousands of HVD's ranging from 5 to 20,000 HP have been used, many in very demanding installations where around-the-clock, 7-day-a-week, operation is required. The oldest HVD's have accumulated over 100,000 operating hours with no more than routine maintenance.

Why have HVD's almost been ignored for movable bridge drives? Two probabilities come to mind: a) the power demands for bridge drives are relatively modest - 30 to 500 HP covers most drives- whereas the industrial HVD was primarily developed to meet the 1000 HP and up applications common in the P2M2 area, and b) the '60's and '70's were a time of intense activity in the P2M2 area, which created little incentive to pursue other potential applications, such as the movable bridge field.

The fact of the matter is that many of the characteristics that made HVD's attractive for P2M2 applications apply to movable bridge drives as well, namely:

Table I

HVD Characteristic

Physical	Functional	Operational
Compact	Clutching	No load start
Lightweight	Braking - dynamic	Unloads motor for start
Weatherproof	static	Allows sequential start
Not position sensitive	failsafe	"Soft" start
	Closed loop control	"Soft" stop
Shockproof	Variable speed	Creep
Vibrationproof	Torque controllable	Inch or jog
Available with wide choice of gearing.	Multi-speed	Accurate positioning
	Load sharing	True 4-quadrant operation
		High reliability
		"Maintainability"

REQUIREMENTS FOR MOVABLE BRIDGE DRIVES

Let's examine typical requirements for movable bridge drives:

These would include:

- Accelerate and decelerate large loads gently and consistently.

- Provide dynamic braking with or without backdriving loads (wind or ice induced)
- Provide safe and consistent stopping. High positioning accuracy required, especially for railroad bridges.
- Provide high reduction gear ratios, with parallel or right angle outputs.
- Accomodate special requirements, such as multiple drive inputs.
- Accomodate either auxiliary power emergency drives or manual emergency drives.
- Meet widely varying ambient conditions, ranging from tropical to arctic, including salt water spray and occasional immersion.
- Be reasonably compact.
- Be highly reliable, yet simple to maintain. In-situ routine maintenance a must.
- Meet all local and federal codes.
- Be long-lived. 35 year life typical.

Comparing the above list with Table I, it can be seen that the HVD developed for the P2M2 applications can be used almost "as is" for movable bridge drives.

Thus, HVD's for movable bridges benefit from the large body of hardware and application experience accumulated over the last 20 years in P2M2 areas.

HVD BASICS

Before proceeding with applications details for movable bridges, a brief review of HVD basics may be in order.

Fig.1 shows the basic elements of a HVD. The input shaft on the left is driven at fixed speed by the prime mover, which may be an induction or synchronous motor, if the primary source, or a battery powered motor or IC engine,if the backup or emergency source.

The output shaft may operate from rest to the maximum, or input speed. An important characteristic of the HVD is the ability to operate without slip - the output shaft is directly coupled to the input shaft at top speed.

The "brains" of the HVD is the electronic controller, which continuously compares the output variable, say speed (in a tachometric feedback system), with the desired value, and sends corrective signals to the actuation system.

The actuation system is responsible for converting the electronic "commands" into a torque change, for the controlled variable in a HVD is torque, no matter what process variable is desired (speed, torque, power, etc.)

As shown in Fig.2, a servovalve, a fixed displacement pump (motor driven), and accessories such as filters, heater, reservoir, make up the electric to hydraulic conversion system, while the final control element is a single acting, spring return cylinder, which is built into the drive itself.

The servovalve is the key element in this system, and works as follows:

- o The output of the controller is a DC current which produces a proportional force "F"
- o Force F, thrusting against the nozzle/flapper assembly (one end of the armature forms the flapper), generates a proportional pressure "p"
- o Pressure p (which can never exceed the supply pressure produced by the pump of about 80 bar) acts on the cylinder
- o The cylinder produces a clamping force on the discs proportional to the pressure
- o Because of the proportionality between DC current, force F, pressure p, and clamping force, and finally, the nearly linear relationship of torque to clamping force, HVD torque closely follows controller output current.

Both non-linearity and hysterisis exist, of course. Therefore, closed loop control is recommended for all but the simplest applications. The addition of closed loop controls "linearizes" the control because of the continuous corrective action that occurs as the output is compared to the setpoint.

In the basic scheme shown in Fig.1, a proximity probe converts output speed to a proportional frequency, which the frequency converter transforms into an analogue signal for control and display (although direct digital speed indication is easily accomodated).

Fig. 3 and 4 illustrate variants of the basic HVD that are frequently required for bridge drives. Both variants incorporate hydroviscous brakes, Fig.3 showing the spring applied brake that is capable of both dynamic and static braking, and Fig.4 the power applied brake that is sometimes specified.

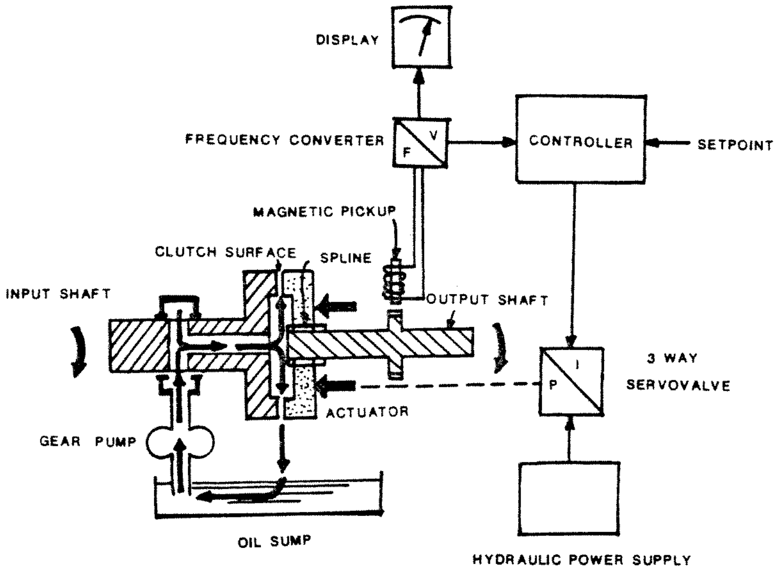


Fig. 1

BASIC HYDROVISCOUS DRIVE SCHEMATIC

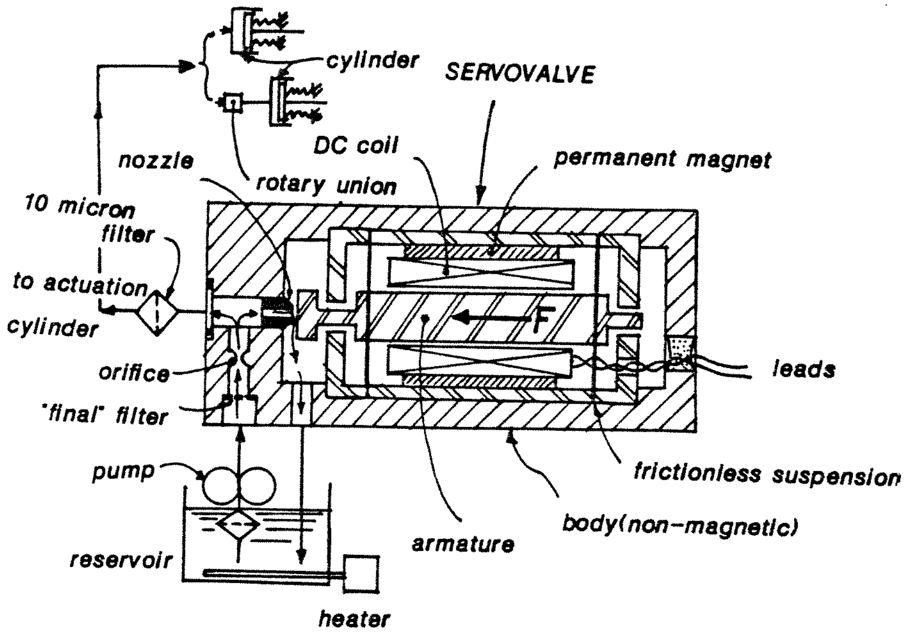


Fig. 2

HVD ACTUATION - HYDRAULIC POWER SUPPLY SCHEMATIC

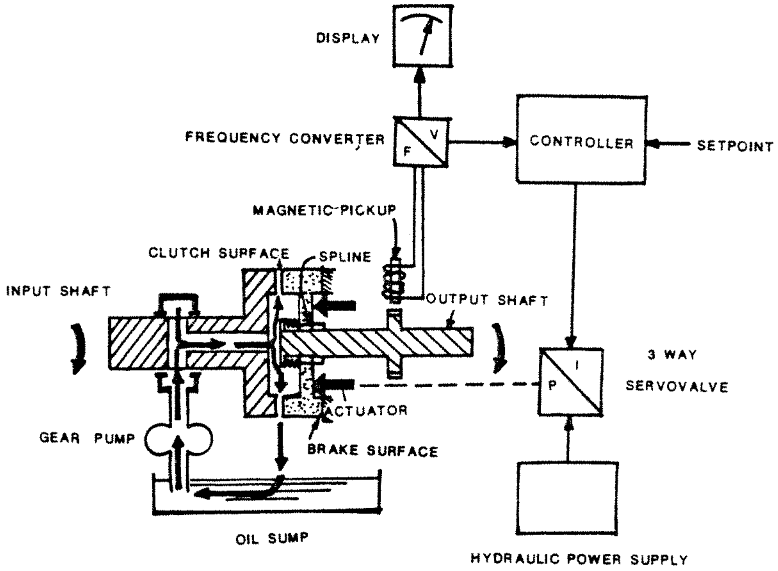


Fig. 3

HYDROVISCOUS DRIVE WITH BRAKE (Spring Applied)

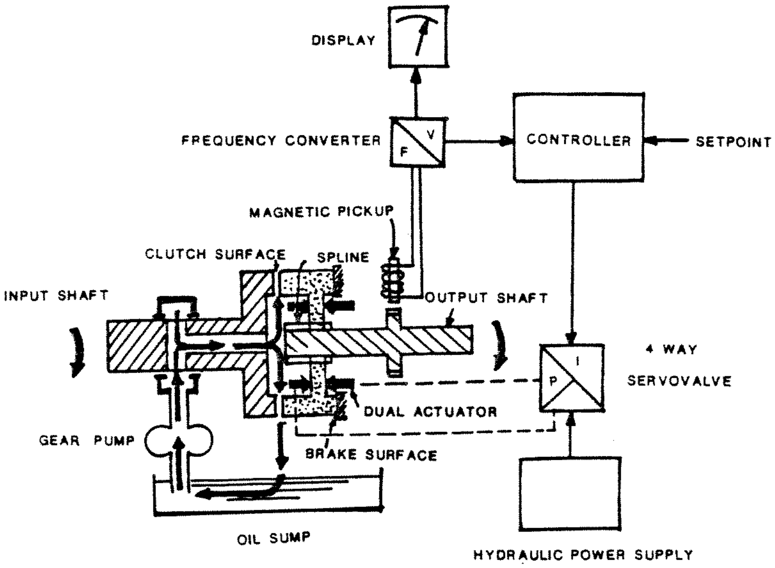


Fig 4

HYDROVISCOUS DRIVE WITH BRAKE (Power Applied)

Fig.5 reduces the HVD scheme to block diagram form, showing clearly the elements comprising the closed loop for speed control, while Fig. 6 shows the block diagram for a frequently used variation, where closed loop control is switchable from speed to power or"kw" control. This is common for drive systems which are power limited, i.e., where the drive motors are sized very close to their operating limits, and therefore need to be protected against overload by a more direct scheme than overload cutouts.

For example, a bridge drive system might be designed with dual drive motors for normal operation. In the event that one motor is inoperable, it may be desired that the bridge operate with a single motor, albeit at reduced acceleration rates (longer lift time). In this case, the scheme in Fig. 6 would be used in the speed feedback mode for normal, and in the kw feedback mode for emergency operation.

ACTUATION SYSTEM STANDARDIZATION

An interesting and useful fact to remember is that HVD actuation systems (controller and hydraulic control package) are not only low power consumers - 25 watts for the electronics, plus another 500 watts or so for the hydraulics - but are completely standardized and therefore interchangeable for every HVD (of a given manufacturer). The author's company, for example, offers the same actuation package for 5 to 10,000 HP.

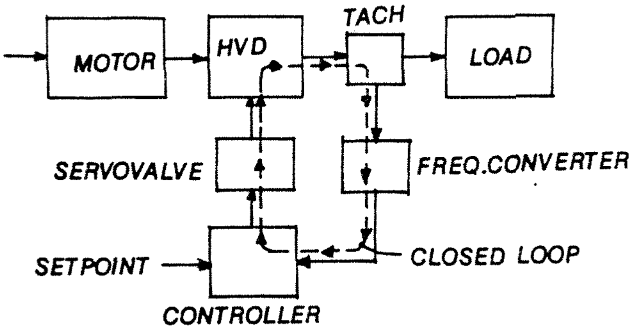
Similar attempts have been implemented for the electrical power requirements. The system described here accepts any voltage and frequency commonly used in the world.

THE HYDROVISCOUS DRIVE PRINCIPLE

Having described the control system, let us go back to the basic torque transmitting principle. As the name implies, HVD use the viscous shear between closely spaced discs to generate torque. For clarity's sake, only a single working surface is shown in Fig.1, 3 and 4, while in practice from one to over thirty surfaces are used.

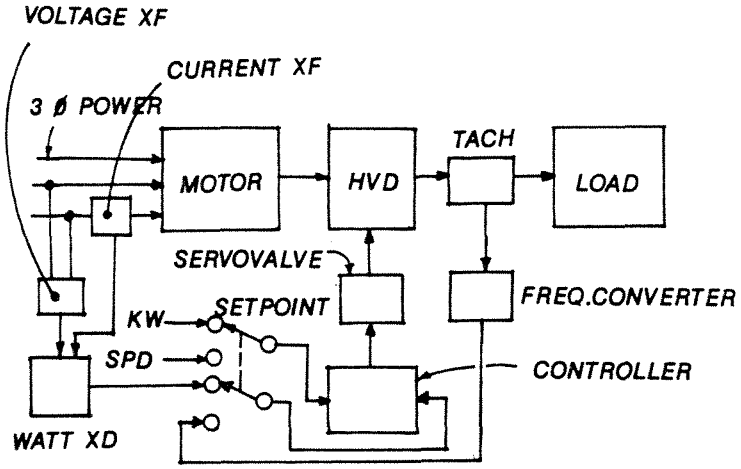
Oil, usually a lightweight additive type known as ATF Dexron (the same oil used in the majority of automatic car and truck transmissions), is continuously circulated through the HVD. A fixed displacement pump sucks the oil out of the sump or reservoir, injects it into the hollow shaft, from which it enters the hollow hub on which one set of disc are mounted, enters the surfaces between the discs, and sprays out of the discs and back to the sump or reservoir.

As in all controlled slip drives, the slip energy is converted into heat, which is transferred to the atmosphere via a



HVD SYSTEM with SPEED CONTROL

Fig 5



HVD SYSTEM with SPEED AND KW CONTROL

Fig 6

radiator, or, if water is available, to the water via a heat exchanger.

As mentioned earlier, HVD torque is controlled by controlling the disc clamping force, and lockup,i.e., direct coupling of input to output shafts, is achieved by increasing the clamping pressure until friction alone carries the load.

HVD ARRANGEMENTS & CONFIGURATIONS

HVD's can be used singly or in conjunction with an extremely wide variety of reducers. The basic building block is the flanged HVD shown in Fig.7, or its free-standing cousin, which differs only in that the output shaft, instead of being supported by the reducer bearings, has its own bearings which are located, together with the input shaft and disc pack, in a base mounted, common housing.

Fig.8 illustrates some of the wide variety of configurations available by mating the basic HVD to main and auxiliary gear drives. Fig.8A & B show some of the configurations: 8A-HVD with triple reduction reducer, 8B-HVD with right angle reducer. As may be seen, there are practically no limits to orientation, ratios, mounting, nor, of course, speeds or power.

Fig. 9 and 10 are cross-sectional drawings of only two of the most common configurations, both parallel shaft, mutiple reduction units.

Fig.9 shows a triple reduction geared HVD (known as a GearPakⓡ in the trade), with double extended output shafts, shaft driven pump, and quillshaft mounted HVD.

Fig.10 shows a triple reduction GearPakⓡ with HV clutch and spring applied brake. The brake is capable of both dynamic and static braking. A gear driven lube pump is incorporated as well, so that the only other motor driven accessories are the actuation pump and thermostatically controlled fan for the radiator. Finally, Fig.10A shows how several drives and gearboxes are combined to make up a complete bridge drive, New configurations, such as planetary and star gear versions, are continuously being developed for HVD's, the end result being a more cost effective drive for the application.

HVD OPERATION - MOVABLE BRIDGE APPLICATIONS

In general, movable bridge operations closely resemble large conveyor operations. Load inertias are always very large relative to drive inertia, acceleration (starting) times are quite long, fail-safe brakes and dynamic braking is required, with brake torque equal to or larger than clutching torques, output speeds are very low, and hence demand very high torques, and the drives must inevitably operate in

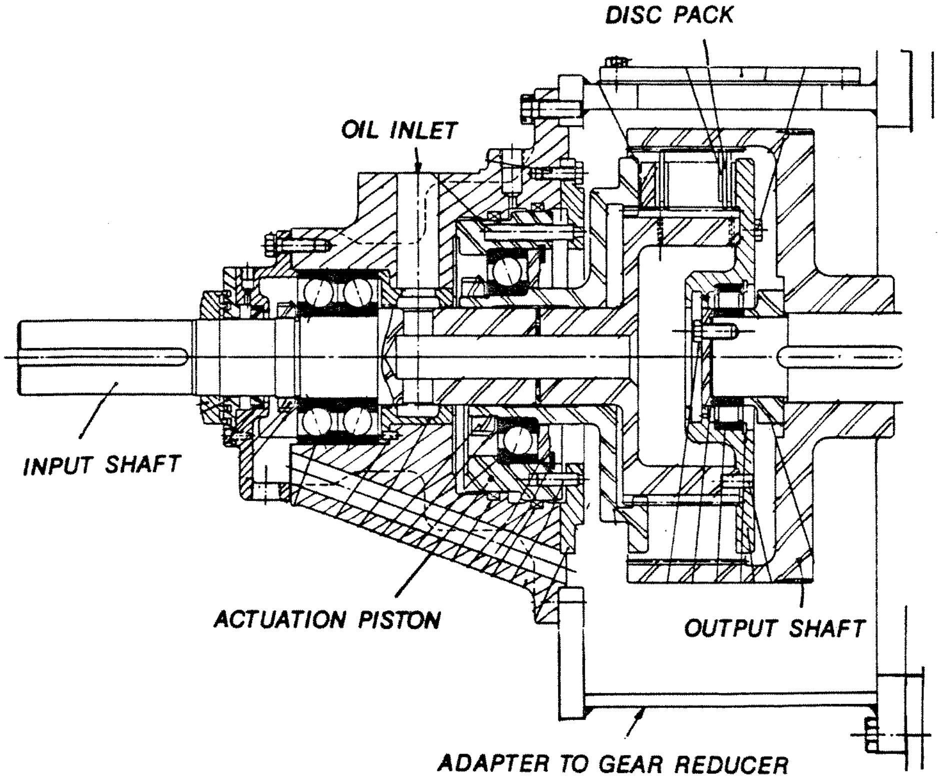


Fig.7

FLANGE MOUNTED HVD

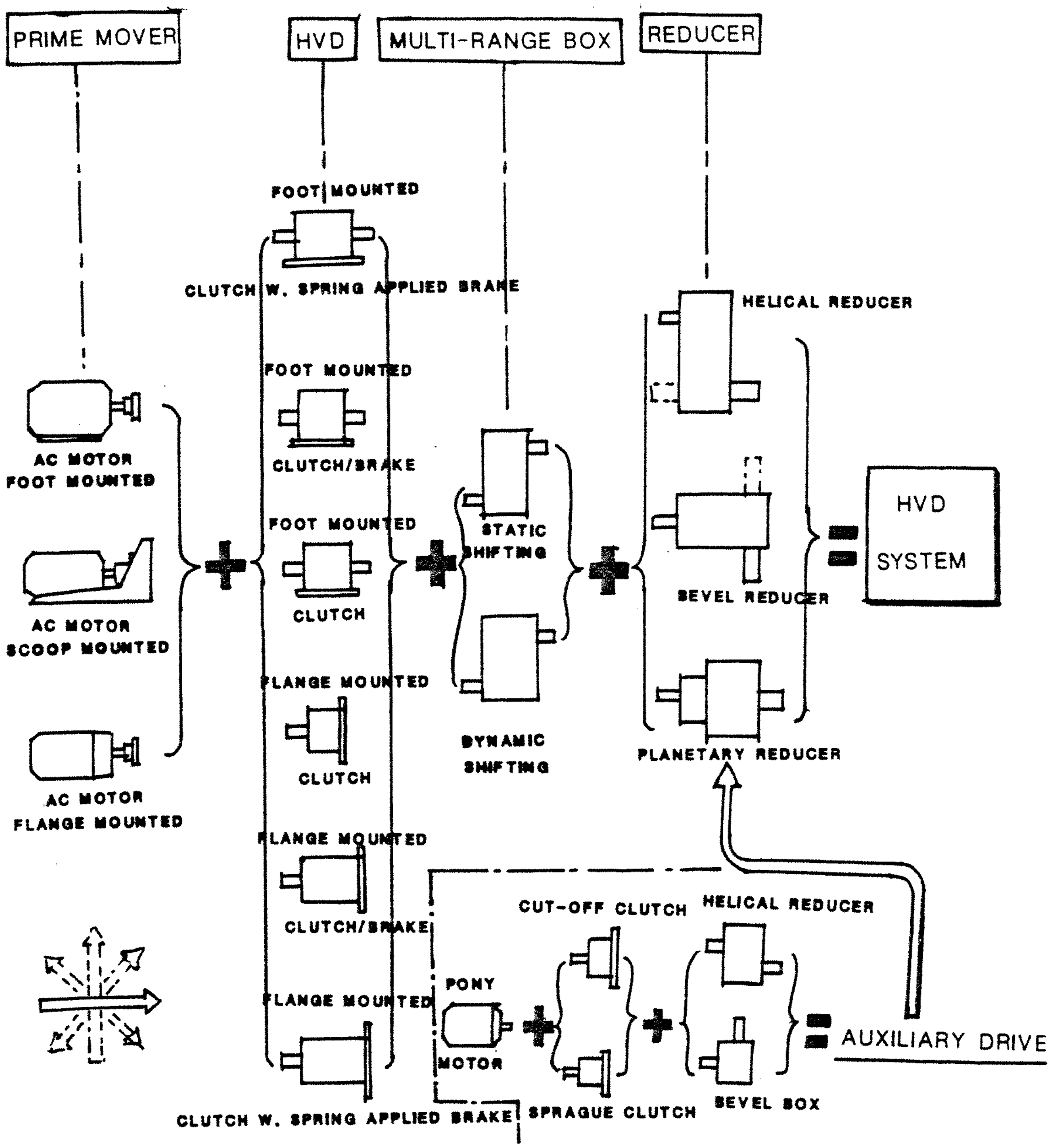
a widely fluctuating and sometimes hostile environment. Perhaps the only negative conditions that are not duplicated are the often hazardous, i.e., explosive or abrasive atmospheres, that occur with conveyors.

Fig.11 shows a typical operating profile. Note that the drive motor starts and stops unloaded, and may be shut down during a prolonged dwell, although for dwell times of 10 minutes or less, it may be desirable to keep the motor running to allow it to cool off.

The HVD controller allows both acceleration and deceleration times to be adjusted. Once set, these times are very accurately held by internally generated DC voltage ramps and the speed feedback circuit, regardless of load fluctuations.

DYNAMIC BRAKING

If overhauling loads are anticipated, such as ice or wind induced overrunning moments shown in Fig. 12 and 13, then dynamic brakes must be specified. Dynamic braking may be accomplished in one of two manners:



HYDROVISCOUS DRIVE SYSTEM SCHEMATIC

Fig 8

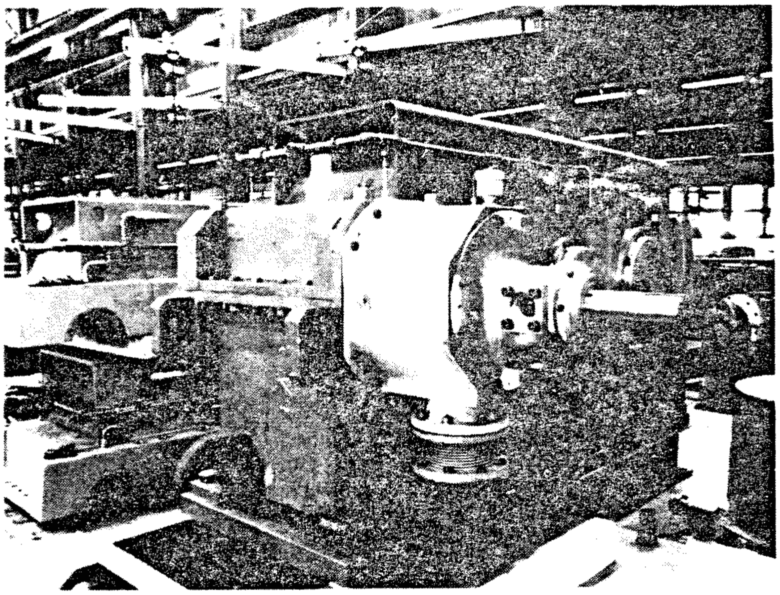


Fig 8A: HVD with Triple Reduction Parallel Shaft Reducer

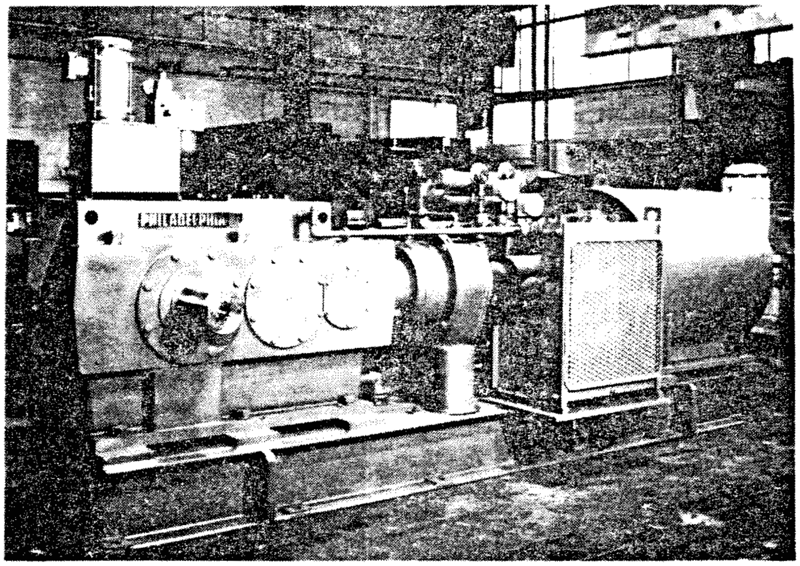


Fig.8B: HVD with Right Angle 2-Stage Reducer

(Note radiator on right and Actuation Unit on top of reducer on left)

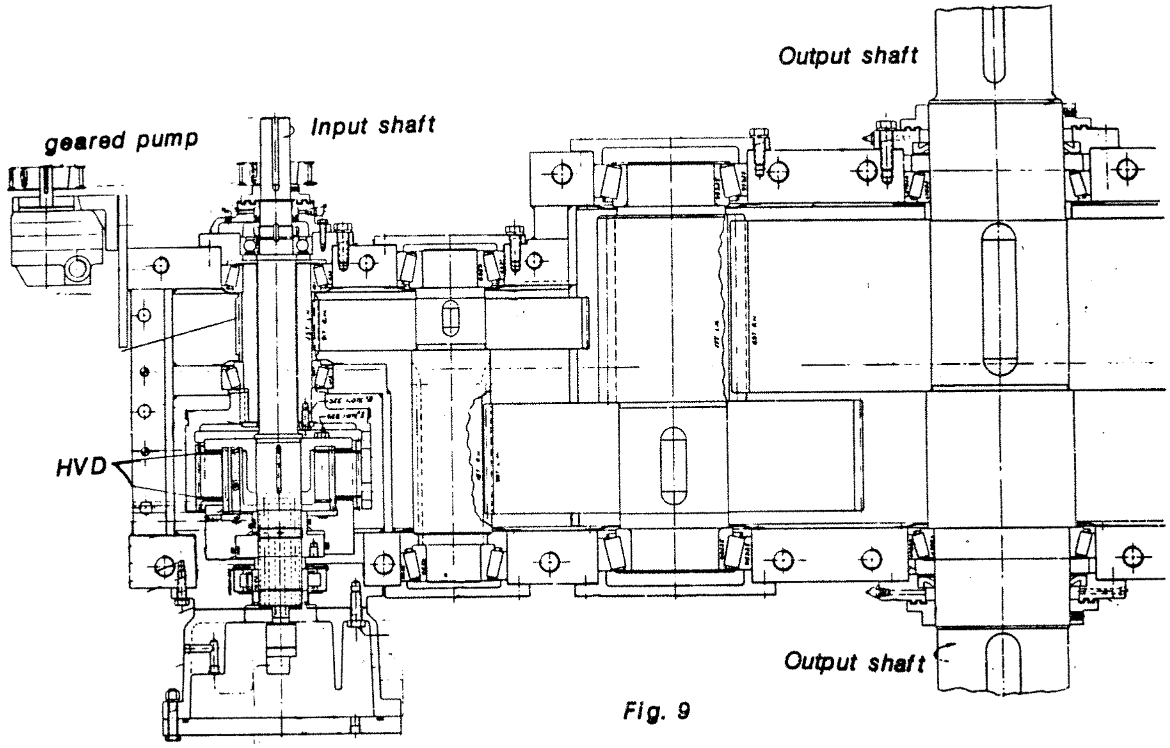


Fig. 9

TRIPLE GEARED HVD

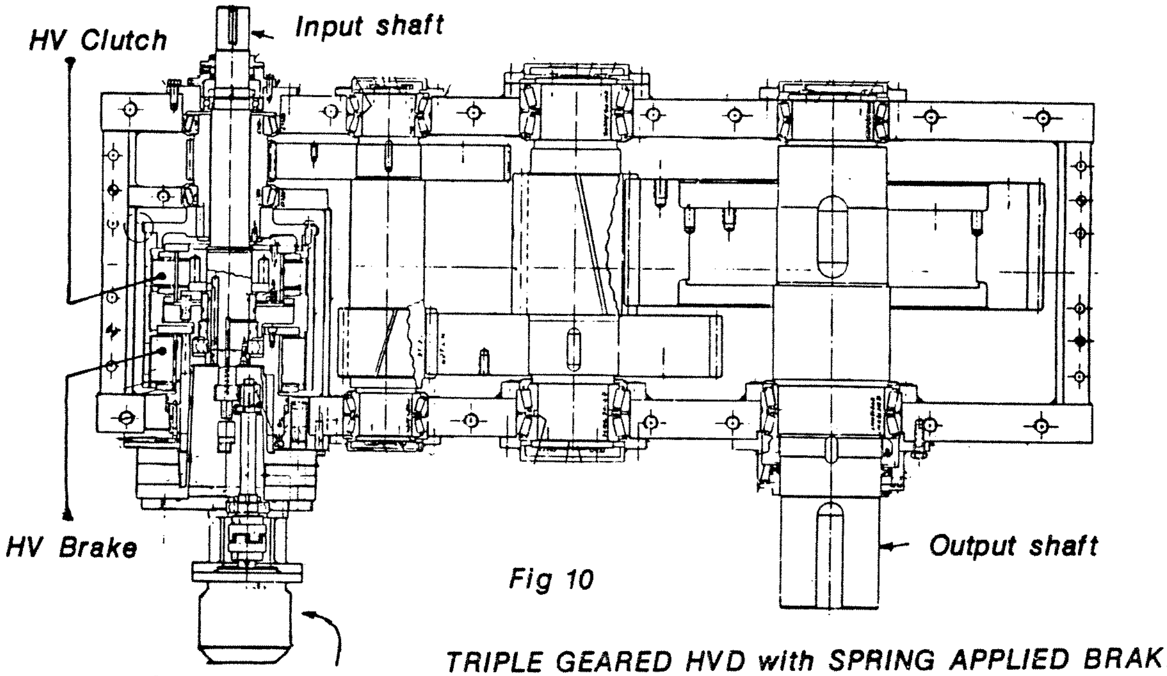


Fig 10

TRIPLE GEARED HVD with SPRING APPLIED BRAKE

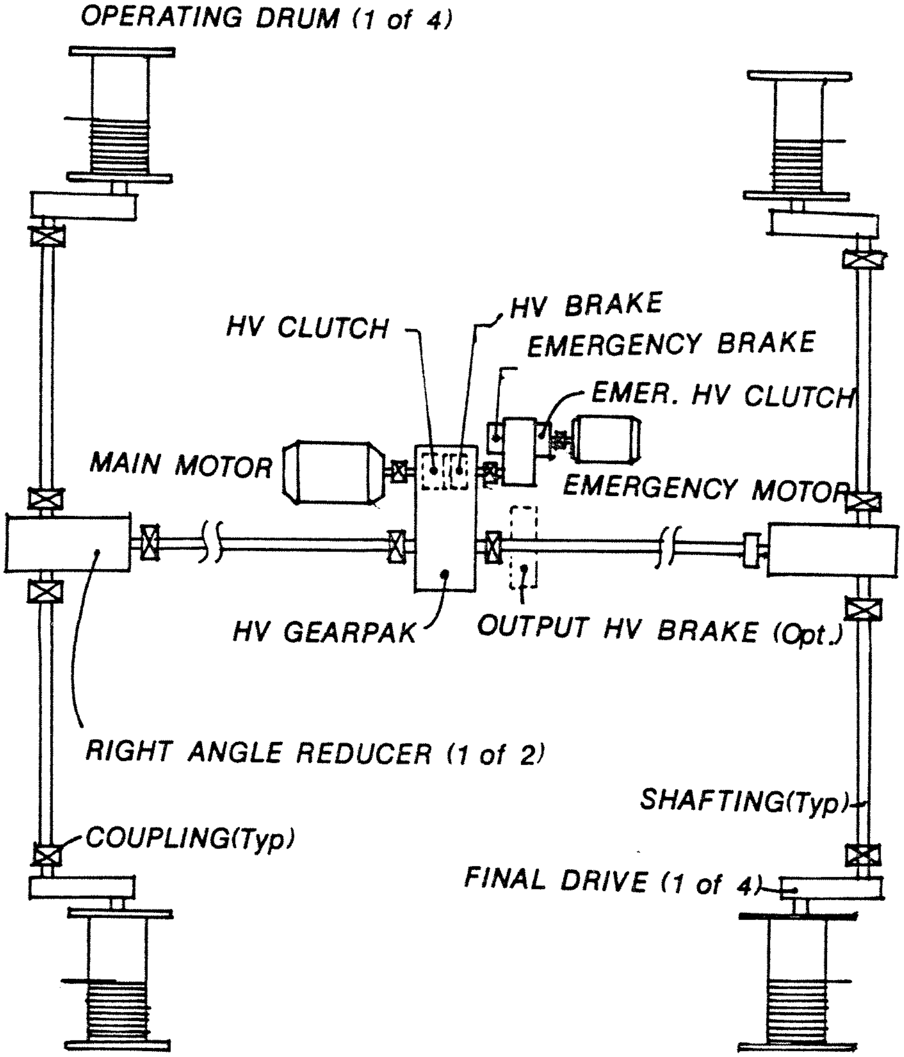
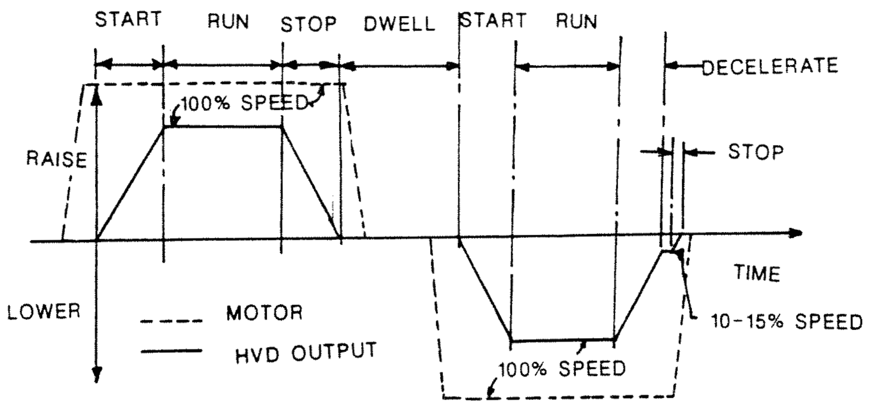


Fig. 10A

TYPICAL HV BRIDGE DRIVE SYSTEM SCHEMATIC



TYPICAL OPERATING PROFILE

Fig 11

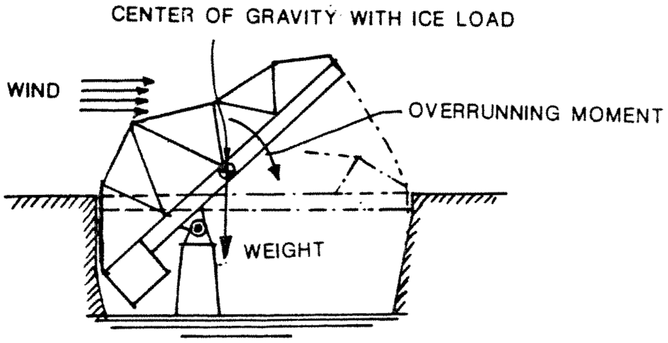


Fig 12

BASCULE SPAN LOADING DUE TO WIND AND ICE

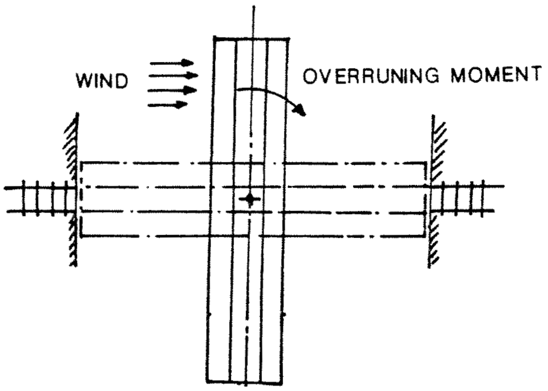


Fig 13

SWING BRIDGE LOADING DUE TO WIND

1) The HVD may be locked up, forcing the AC motor to absorb power as an induction generator, or

2) The HVD may incorporate a HV brake, as shown in Fig. 3 and 10, that absorbs power in a controlled manner.

In the first case, the absorbed power is fed back to the power lines, and the power (torque) limit is set by the pullout torque characteristics of the motor. Typically, up to 150% pullout torque may be safely exerted.

In the second case, the power absorbed is converted by the HV brake into heat, which is then dissipated in the same cooling system described earlier for the HVD. In this case, no limits exist for the braking torque - this may exceed the motor pullout torque.

Lowering speed in the presence of backdriving loads depend on the type of dynamic braking applied. If the AC motor is used, its backdriven speed can vary from synchronous to aprox. 5% higher, assuming a NEMA design A or B motor is used, and as much as 7% higher for a NEMA C motor. In any event, this range of lowering speed variation is adequate for bridges.

If a HV brake is used, the closed loop speed regulation will be on the order of ±1% of the setpoint speed.

POSITIONING ACCURACY

Positioning accuracy is essential for railroad bridges and to a lesser extent for highway bridges. Rapid closing and accurate positioning impose conflicting requirements that in difficult cases can be readily resolved using a 2-step braking procedure:

1) The bridge is first decelerated from top speed to an intermediate speed around 10-15% of the top closing speed.

2) Shortly after the intermediate speed has been reached, final braking is applied to bring the bridge to a full stop.

Since stopping from the intermediate speed only imposes a kinetic energy on the brake of one to 2% of the full speed energy, the system can be brought to rest to a final accuracy of ± 1/32", provided that the timing errors for the brake valve are minimized through the use of solid state switching, and likewise, the position sensors or limit switches are selected with due considerations for repeatability.

MAINTENANCE

Since the HVD is basically a mechanical device, maintenance can be performed by the average mechanically trained crew.

The use of replacable element oil filters allows quick filter changes, and critical filters are oversized so that filter changes are required no more than yearly.

If the HVD is located in a difficult area, remote oil level and filter status indicators can be supplied.

Since ATF Dexron is an all-weather oil, seasonal oil change is not required. Based on previous experience, HVD oil changes, provided oil contamination is prevented by specifying the proper breathers, can be scheduled for intervals of 5 years or more.

The electronic controller is designed so that all key circuitry is on easily replacable cards that are keyed so that they will only fit in their proper slots. The use of high temperature components, conformal coatings, 100% burn-in of PCB's, and other high reliability design features results in design MTBF's as high as the mechanical components of the HVD.

Well marked and easily accessed test points allow quick fault isolation in the event of control problems, and faulty PCB's can be replaced in a matter of minutes.

The servovalve is installed on a manifold using 2 bolts and 0-ring seals. It, too, can be replaced in a matter of minutes if needed.

SUMMARY

The HVD is a versatile mechanical drive that, because of its closed loop electronic controller, and HV brakes, can provide the true 4-quadrant operation with"soft" starts and stops required for movable bridge drives.

Hence it offers a cost-effective alternative to all-electric (DC or variable frequency) drive systems or hydraulic drives.

While the HVD system does use both electronics and hydraulics, its power requirements and complexity are far below those for the all-electric or hydraulic approach, thus making HVD-based systems readily maintainable by the average mechanic.

The wide variety of reducers and auxiliary drives available for HVD's makes sourcing drive system suppliers simpler and narrows down the responsibility for drive system performance.

BIBLIOGRAPHY

1. Liu, John K. "Development and Application of HVD's" ASME Paper 74-DE-6, April 1974.
2. Liu, John K. "HVD Controls - What's Needed, What's Available" Nat.Conf. on Power Transmission, Houston,TX. Nov.1982.
3. Liu, John K."Recent Devlopments in Conveyor Drives" Nat. Conf. on Power Transmission, Chicago, IL. Nov.1979.