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ROTARY HYDRAULIC SUSPENSION DAMPER
FOR HIGH MOBILITY OFF-ROAD VEHICLES

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ABSTRACT

In order to achieve high mobility over off-road terrain, a vehicle suspension system should combine adequate wheel travel with a high level of damping force. The device described is a suspension damper which utilises the rotational movement inherent in most vehicle suspension systems to generate large damping forces proportional to vertical wheel velocity. By use of modern hydraulic technology a compact design with high level of thermal dissipation and immunity from foreign object damage has been achieved.

The device was developed, in the first instance for use with a torsion bar suspension system on a military tracked armoured personnel carrier. In this application, high levels of performance and reliability have been demonstrated. However, the technology is readily applied to other types of suspension typically used on wheeled or tracked vehicles and examples of such applications are described.

INTRODUCTION

When considering the performance and economy of a vehicle on good roads the performance of the suspension system is not normally of prime importance. However, in the off-road environment, the performance of the suspension is an essential factor. Examples of vehicles having good power/weight ratios (and hence good "on road" performance) but very poor off-road performance are manifold. Such vehicles are commonly unable to utilise their available power due to the level of discomfort induced by traversing even modest terrains. Fuel economy under these circumstances is obviously unsatisfactory as the drivers reaction will be to decelerate when pitching becomes excessive and to accelerate again once relative stability is restored. It is arguable that in such cases a more satisfactory vehicle would be one that used a lower rated power pack together with an improved suspension system.

What then constitutes a good suspension system for an off-road vehicle? Off-road terrain is typically a random series of undulations of varying pitch, the amplitude of which is significant as compared to the diameter of the road wheel. Vehicles designed to cope with typical off-road terrain, should maximise available road wheel travel and incorporate a high level of damping.

The function of a damper is to absorb energy imparted to the road wheel. Analysis of a spring-mass-damper system show that damping should be proportional to the velocity at which the wheel is being displaced. However, if a high damping rate is to be used, in the case of a very large wheel velocity, excessive suspension forces may be generated. In order to prevent such excessive forces it is normal to incorporate a relief valve or similar device to limit the magnitude of the damping force induced. It is generally accepted that in order to give adequate ride characteristics, this limit should exceed the static wheel load by a factor of 1.5 to 2. This means that the vast majority of suspension events will result in proportional levels of damping force and only the rare "high-speed excursions" will result in constant force due to relief valve "blow-off".

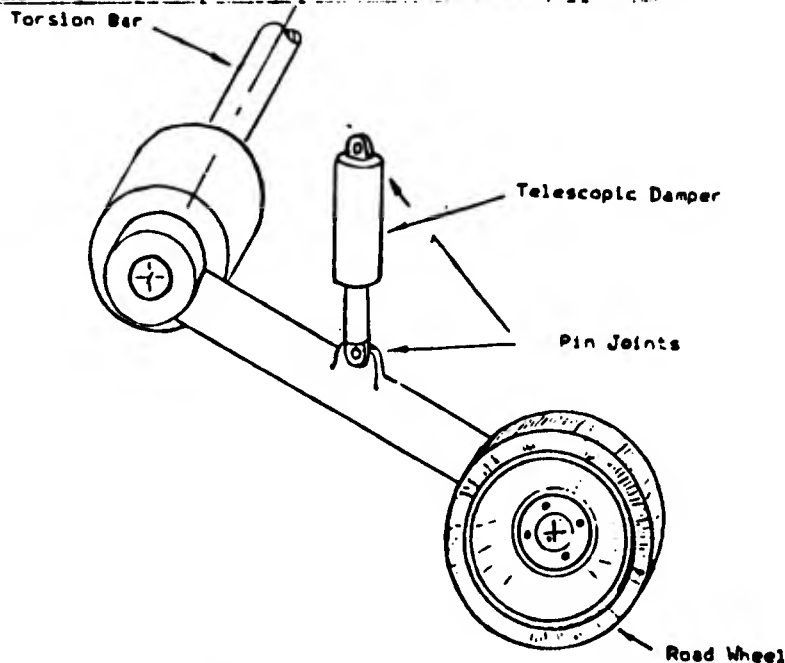
Damping forces of the order described infer very large energy levels to be absorbed. The damper converts the mechanical energy into heat. Therefore, in order to prevent overheating, a high performance damper for an off-road vehicle must dissipate such heat very effectively.

The main source of ride discomfort is vehicle pitching. This results from excitation of the pitch mode natural frequency of the vehicle. This is typically very low (c 1 Hz). Oscillation of this type must be adequately damped. However, it is undesirable that a damper should respond positively to the higher frequency, small amplitude oscillation induced by passage over cobblestone surfaces (or, in the case of tracked vehicles, track links.) Response to these would result in unwanted energy dissipation.

Current Suspension Systems

Most vehicle suspension systems involve linkages which convert the vertical motion of the road wheel into an angular movement. Common examples of this are the trailing arm and the wishbone types of suspension. However, most suspension dampers currently in use are of the linear, piston type. Thus the angular movement of the suspension member is reconverted to a linear motion. (Fig 1)

Fig 1. Linear telescopic damper installation (Typical)



The most common linear suspension damper is the hydraulic telescopic unit which is pin-jointed to the suspension arm and to a fixed point on the vehicle. Although this type of unit is adequate for most road vehicle applications it suffers from a number of disadvantages when considered for off-road operation:

(i) In order to provide damping forces of the order required it is necessary to have either very high internal pressures or a very large piston area. This, combined with the large amplitudes over which damping is required, results in a very bulky unit which may be difficult to engineer into a vehicle installation.

(ii) As mentioned above, the large damping forces which are required result in a large amount of thermal energy to be dissipated. This can only be conducted away via the pin joints, and any radiation heat loss, particularly when the unit is covered with mud, is very small. Thus, sustained operation over typical cross-country terrain is liable to result in overheating and failure.

(iii) The typical location of telescopic dampers means that, dampers are exposed to debris being dislodged by the roadwheels and damage to the damper due to ingress of such debris is common.

Linear dampers may be used with any type of spring e.g. coil springs, torsion bars, leaf springs etc. A recent development of the piston principle is, however, the hydro-pneumatic unit which incorporates a gas "spring" with a hydraulic damper. A unit of this type has been developed for the latest British Main battle tank "Challenger". Although this type of unit overcomes some of the problems encountered with the telescopic, it is not immune from overheating problems and can only be produced within a viable space envelope by the use of very high hydraulic pressures (9000lbf/in²-62MPa)

This requires the use of complex (and expensive) technology to achieve acceptable levels of reliability and durability.

ROTARY DAMPERS

In view of the above, the development of a damper which would utilise the inherent angular movement of suspension systems, has been considered desirable for some time. This is particularly true in the fields of tracked military vehicles where a large number of vehicles utilise transverse horizontal torsion bars as a springing medium connected to the road wheel by a trailing arm. It is believed that rudimentary rotary damping has been used on some Soviet tracked vehicles and indeed the West German Leopard II is fitted with rotary friction damper. However, the first known use of a hydraulic rotary damper is the U.S. Abrahams M.1. tank.

Horstman Defence Systems Ltd have been involved in vehicles and sub-systems for almost 70 years. Indeed, the company's founder, Mr. Sidney Horstmann patented and gave his name to a bogey-type suspension which has been used on many types of vehicle up to and including the "Chief-tain" tank.

Rotary Damper for MCV 80

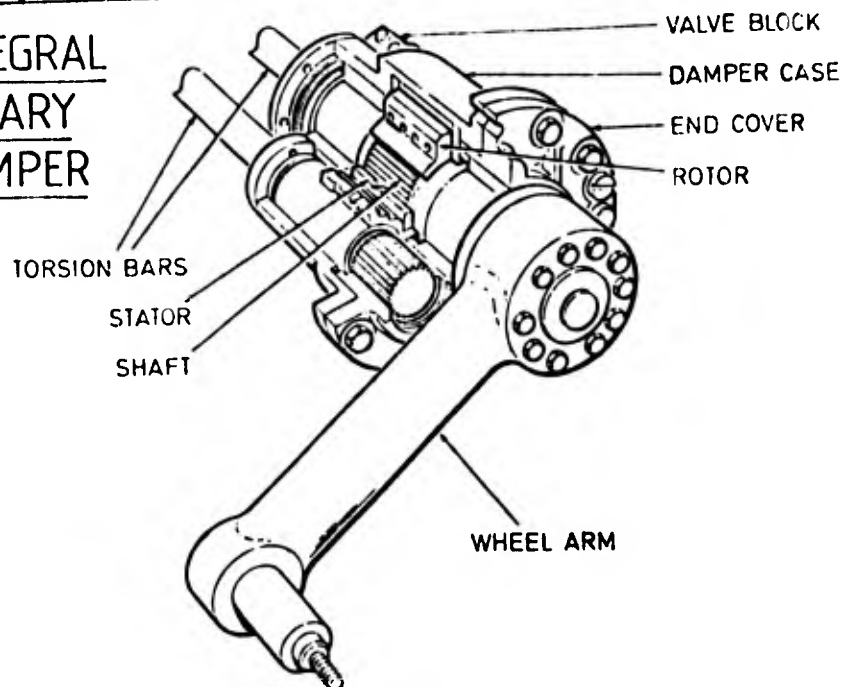
In 1978 Horstman won a contract to design and develop a rotary suspension damper for the MCV80 vehicle. This vehicle has a design weight of 23.5 tonnes and is tracked with 12 road wheels. It is required to carry a section of ten infantrymen including driver, commander and a gunner for the turret mounted 30mm. cannon. It is intended that in service the vehicle would operate in consort with battle tanks and as such must display comparable mobility. This is no mean requirement, as the battle tank's greater overall length renders it less susceptible to pitching over a given course. Thus, in suspension terms, the requirements for MCV80 exceed those required of its accompanying battle tanks.

Design Requirements

In order to give MCV80 the required mobility a wheel travel of 400mm was specified. The design requirement to be met by Horstman was to design a damper capable of allowing wheel travel of this order, whilst providing the required damping rate up to the blow-off level necessary for the specified mobility. The vehicle has been designed and developed by GKN Sankey Fighting Vehicle Operations. Their specification called for a hydraulic damper to be mounted at the axle arm pivot and to include the necessary bearings. (Fig2) Springing is provided by a horizontal torsion bar passed thro the centre of the damper. The bar is anchored by the housing of the corresponding wheel station on the opposite side of the vehicle.

Fig 2 Integral Rotary Damper.

INTEGRAL
ROTARY
DAMPER

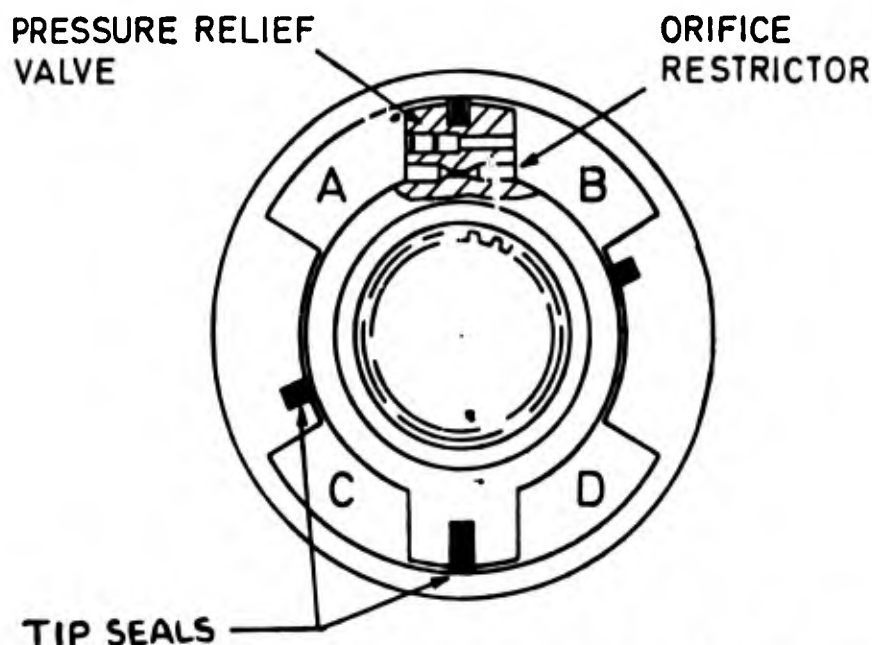


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Description of Unit

The Horstman Rotary Hydraulic Suspension Damper is in concept similar to a two vane rotary actuator. Two vanes are attached to a rotating hub and a further two to an annular stator casing. This effectively creates four discrete fluid cavities. (Fig 3). Whereas, in an actuator, pressure is applied to diagonally opposite cavities to generate rotational movement, in the damper, rotation of the hub results in pressure being generated in the two cavities which are diminished by the rotational movement. The damping rate is determined by the rate at which fluid is allowed to leak from the pressurised chambers across the rotor vanes, via seals, orifices and valves.

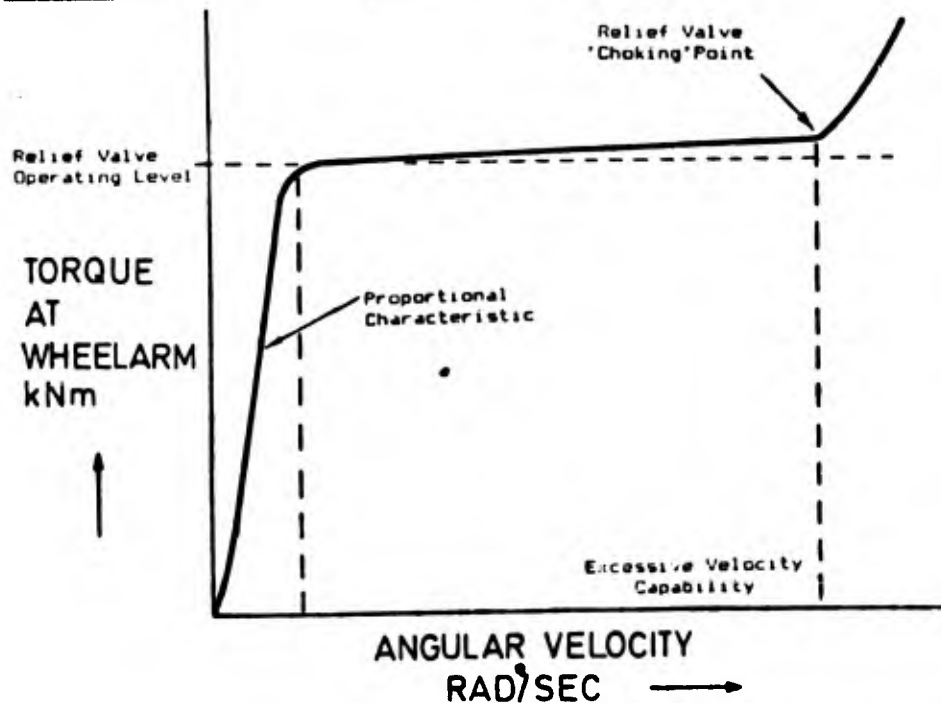
Fig 3. Section through Damper Cartridge.



Conventional rotary actuators require near-perfect sealing. This is achieved by complex elastomeric elements and an extremely rigid structure. This results in a relatively heavy unit which must function at modest pressures and angular velocities in order to achieve adequate seal life. However, in a rotary damper application, perfect sealing is not of paramount importance. Angular velocities may also be an order of magnitude higher than those generally specified for actuators. Further, as this is a vehicle application, it is desirable to minimise weight and hence to design the structure for the required life and not to preserve rigidity under all circumstances. These requirements demand a sealing system different from those used in rotary actuators. Horstman Defence Systems have developed a sealing system capable of satisfying these somewhat unusual requirements. This system does not give perfect sealing, allowing a small rate of leakage across the vane. This leakage flow is laminar and therefore highly temperature dependent.

In order to minimize this dependence a fixed orifice is incorporated in the rotor vane producing a substantially temperature independent flow path. The combination of the "parasitic" leakage around the vanes and the orifice flow gives an almost linear damping rate. This rate is only dependant on fluid temperature to a small extent. By close attention to the detailed engineering of the seal system, it has been possible to achieve a damping rate which satisfies the stiff damping characteristic considered necessary for this vehicle.

Fig 4. Typical Rotary Damper Performance Characteristics.

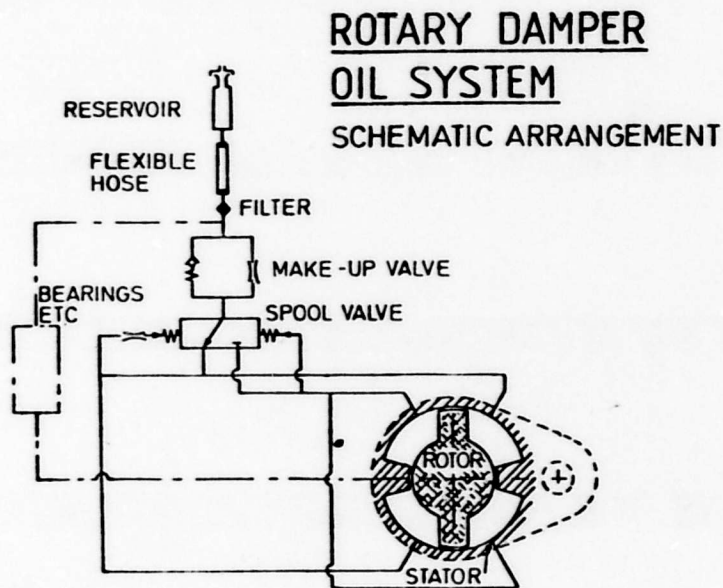


One of the significant advantages of an annular working area is that a relatively large swept volume can be contained within a modest space envelope. This means that large damping torques can be generated by hydraulic pressures of the order considered normal in industrial systems, typically 3000-4000 bf/in² (200-300 Bar). Obviously this is highly advantageous in designing seal systems, however, it does impose severe requirements on the valve system instituted to give "blow-off" at excessive angular velocities. (Fig 4.) It is clear that in order to achieve a relatively "flat" characteristic, at vertical wheel velocities of several metres per second, a very large volume of oil must be transferred across the rotor vane once the blow-off pressure has been achieved.

This function has been satisfied by the use of a number of pressure relief valves incorporated in the rotor vane. A further benefit of this is that dampers can be differentially rated to give higher blow-off in a desired direction. On tracked vehicles it is desirable to have lower blow-off forces in the rebound direction in order that road-wheels do not "hang-up" (i.e. can return quickly to their normal position following a bump, when the only force restoring them is that imposed by the torsion bar or spring.) In order to prevent build-up of internal hydraulic pressure due to rapid cyclic actuation or thermal expansion of the damping fluid, a spool type change over valve is used to vent the non-pressurised chambers to an externally mounted reservoir. (Fig 5)

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Fig 5. Rotary Damper Oil System (schematic).



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The damper unit is flange mounted to the vehicle hull. This is important for two reasons: Firstly, a large area of contact is maintained between the damper unit and the vehicle hull. This permits the vehicle hull to function as a very effective heat sink, dissipating the energy absorbed by the damper. Secondly, this type of mounting allows a very "clean" outside profile such that the damper is well protected from damage due to ballistic attack or terrain debris thrown up by roadwheels and trackwork.

Rig Testing

In order to fully test the rotary suspension damper, Horstman Defence Systems have commissioned a number of special purpose test rigs. The most significant of these is a large electro-hydraulic test stand which is capable of exercising dampers over the entire service range of torques and speeds. In a damper the highest torques are generated by the highest angular velocities. Thus, this test stand has an instantaneous power rating in excess of 300 KW. Other rigs are a performance test rig of more modest rating, and a general purpose, hydraulic, test bench for component evaluation.

Over 4000 hours of rig testing has now been completed. This has covered investigation into all aspects of functional performance, structural integrity and long term durability. Damper units have been fully evaluated against a test cycle compiled from actual vehicle data, covering the prescribed duty cycle. Several such tests of 600 hours duration have been satisfactorily completed, and most recently such a test was continued to 1000 hours without failure. This duration equates to two vehicle "overhaul" lives.

Although it is recognised that such testing cannot replace actual vehicle testing, it allows the damper to be evaluated in terms of durability and performance. This has enabled a high level of confidence to be established prior to the installation of rotary dampers on the customers vehicles.

Vehicle Testing

The first damper units were delivered to the customer in mid 1979 and since that time over 150 dampers have been supplied for testing on prototype vehicles. Over 100,000 Kms vehicle testing has been carried out on Ministry Of Defence testing grounds, and very high levels of reliability have been achieved.

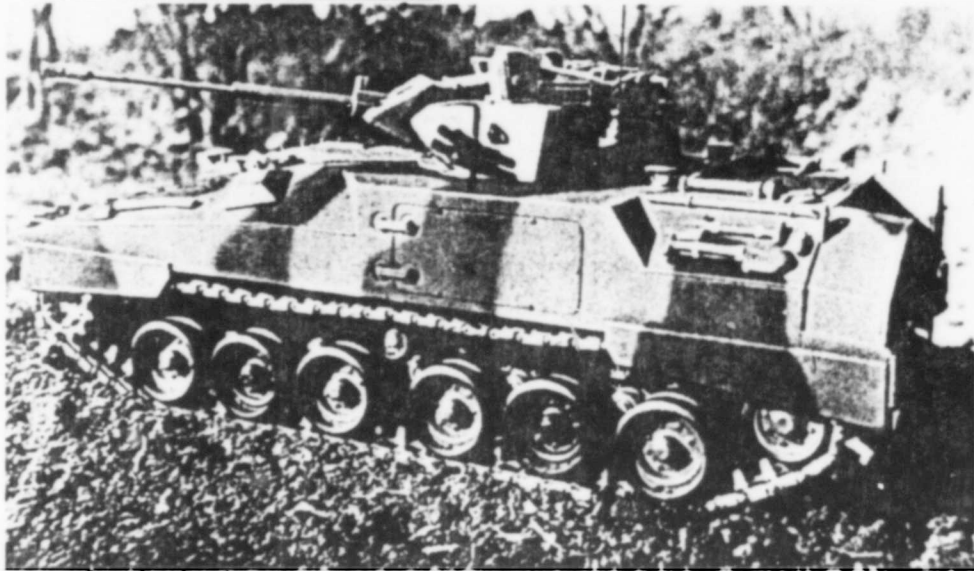
Many independent authorities have commented most favourably on the level of ride comfort that is achieved, even when traversing severe cross country terrain. The suspension performance is reported to be such that the vehicle may be driven at constant throttle and speeds considered to be very high for the type of terrain.

The basic function of an armoured infantry vehicle is to carry infantry, and, as mentioned above, MCV80 carries a section of ten men. It is therefore of great importance that the men being transported should arrive at their dismounting point in a fit state to fight. The suspension of the MCV80 has been fully evaluated in instrumented vehicle testing which has been reported elsewhere. This testing suggests that, in the service environment MCV80's complement will cover the ground more quickly and in more comfort than in other vehicles of this type.

Frequency response testing has shown that, although the damper responds very effectively to frequencies normally associated with pitch oscillation, energy dissipation at high frequencies (30HZ) is very low. Vehicle testing has shown that the suspension is free from the harshness frequently experienced in telescopic dampers at high frequency.

Thermal performance has also been shown to be very good even when operating in high ambient temperatures, and this has permitted conventional elastomeric seals to be used extensively without thermal degradation.

Fig 6. GKN-Sankey MCV80 Vehicle.



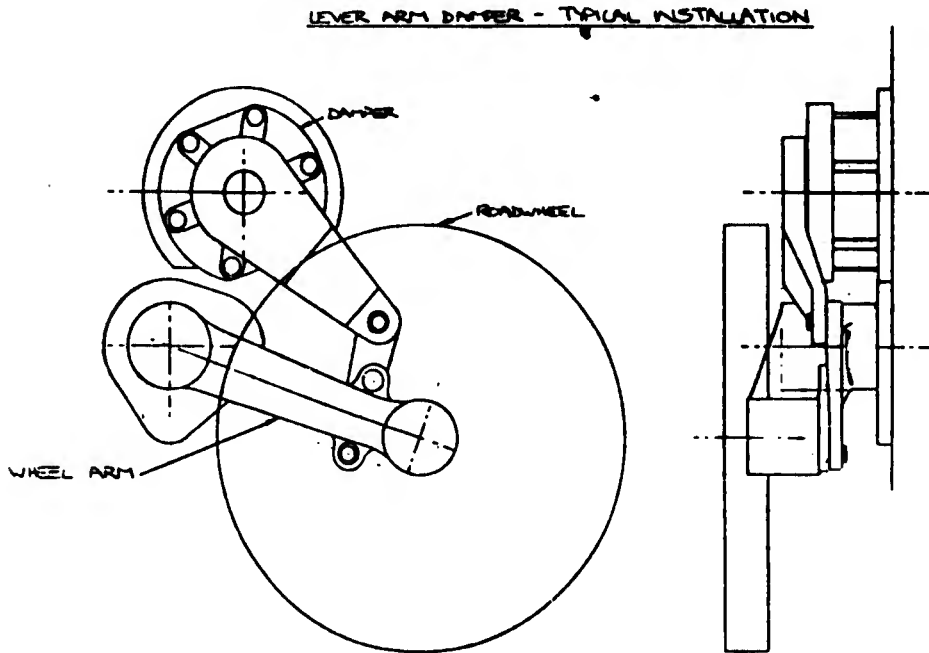
On the basis of this most successful experience, Horstman have now designed a range of similar Integral damper/axle arm units for vehicles across the range of weight from 10-60 tonnes. Of course, each of these designs are applicable to vehicles having horizontal, lateral torsion bar springing, together with trailing arm type suspension. Thus they are most applicable to new designs of vehicle or those where substantial redesign can be undertaken. Obviously this is of little interest to vehicle manufacturers with established designs where the space such a damper might require is already filled. In view of this, Horstman have addressed themselves to the problem of producing a design of damper which is capable of being fitted to an existing vehicle without significant change.

Lever Arm type Rotary Damper

To satisfy this requirement, Horstman have designed a lever-arm rotary damper. Again the concept of lever arm damping is not novel, such units being prevalent on cars and commercial vehicles during the 1950's. However, such units converted the rotary motion of the arm into the linear motion of piston-type units. The Horstman lever-arm rotary unit utilises the sealing technology previously developed for the integral damper units to produce a compact, high performance damper, which can be readily attached to the side wall of a vehicle. The damper lever is attached to the suspension member by a link which may be cranked to allow latitude in locating the mounting face. Also as there is no necessity to pass the torsion bar spring through the centre of a lever-arm damper, the overall size for a given rating can be substantially reduced, particularly at the smaller end of the range.

Obviously, an externally mounted unit cannot be as invulnerable to foreign object damage as the integrated version. However, the rounded shape and detailed design of the external seal render this unit much less vulnerable than a more traditional piston type unit. The flat face on the inboard side of the damper is readily mounted onto the side plate or chassis member to ensure effective heat dissipation.

Fig 7. Horstman Lever-Arm Rotary Damper.



Although this unit has, in the first instance, been designed for installation on tracked vehicles. In principle there is no reason why it could not be installed on wheeled vehicles. Indeed, since angular movement is just as apparent in the suspension of wheeled vehicles, the technology of rotary suspension dampers is of equal relevance. Detailed design of the lever arm unit has now been completed and it is intended to evaluate its performance on several vehicles during 1984.

Horstman Defence Systems Ltd have designed and developed a rotary suspension damper which is capable of providing large damping forces on large wheel travel suspension systems. By the use of modern hydraulic technology a compact design with a high level of thermal dissipation and immunity from foreign object damage has been achieved. The design concept has been fully demonstrated on the GKN-Sankey MCV80, a high mobility armoured infantry carrier.

The technology involved can be applied in various designs to vehicles over a very large weight range utilising the angular movement inherent in most common suspension systems.

The Horstman Rotary Damper provides levels of performance normally only associated with more sophisticated (and expensive) types of suspension. Furthermore, because of the high levels of reliability and durability achieved by this type of unit, a very low "whole-life" cost suspension system can be created.

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ACKNOWLEDGEMENTS

The successful development of the Horstman rotary damper for MCV80 could not have been achieved without very close co-operation with the staff of GKN-Sankey (Fighting Vehicle Operations). Horstman Defence Systems are proud to have contributed to the success of MCV80, which has shown itself to be a most impressive vehicle.

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