Noise Reduction In Hydraulic System Driven By Swash Plate Pump By Optimising Its Control Unit

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Introduction

In view of their high specific power, enhanced static and dynamic characteristics, and lower power requirements, when equipped with control unit to deliver specific flow rate that matches the load, Swash plate pumps are used in wide range of mobile and stationary applications,. However, when equipped with a double feedback control unit implementing a PD controller, the pump generates excessive noise.

Many approaches were followed to reduce the noise at the design stage. Some of these are implementing a pair of silencing grooves.

However, none of the previous studies investigated the effect of the control unit on the noise generation in the pump.

In the present paper, the effect of using a novel control strategy with a single PID controller on noise levels will be evaluated and compared with the current control strategy.

Pump Description

Swash plate pump mainly consists of a swash plate mechanically connected to a finite number of pistons, which are distributed in a circular array, as shown in Figure 1.

The pistons are reciprocating in their cylinders and they are nested in a cylinder block. The fluid traffic from cylinders is controlled by means of a port plate. The length of the piston stroke is determined by the angle of inclination of the swash plate, which is varied by a control cylinder.

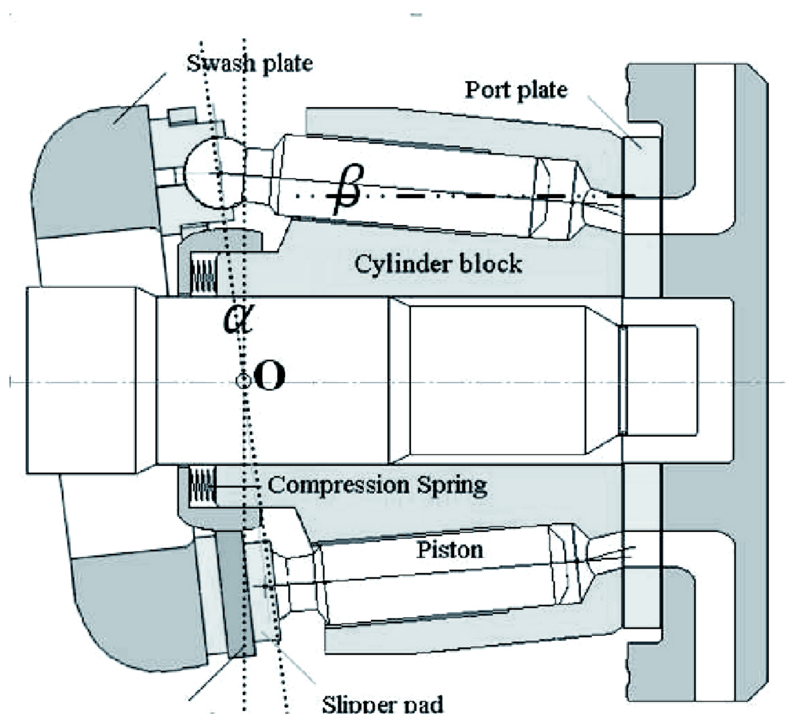

Figure 1: Swash Plate Pump General Structure

Control Unit

In order to save on the pump power and to keep the fluid properties within specifications, the pump is equipped with a control unit.

The control unit determines the swivelling angle of the swash plate and in turn the piston stroke. In order to push the swash plate and generate the required angle, there is a need for two inputs which are a hydraulic input and an electronic input.

The hydraulic input is generated by the hydraulic unit which consists of a secondary pump to generate the pressurized fluid on the control cylinder, and it is connected to the inlet of a hydraulic proportional valve.

The valve has a moving part (spool), its housing (sleeve), and two restoring springs that push the spool against a solenoid.

The solenoid is activated by the control current, which is generated by the electronic part of the control unit.

Control Unit and Noise

There is a relationship between the noise and the control unit, where the type of the controller influences the noise generated by the pump.

The control unit follows different strategies such as PD (Proportional derivative), PID (proportional-Integrative and derivative), PI (Proportional and Integrative), or a combination of them.

It is known that the operation of the pump causes noise, and that noise can be expressed in sinusoidal form, where it has small amplitude and high frequency, as follows:

$$y(t) = A.\sin(wt) \quad (1)$$

where y is the noise, A is the amplitude of the noise, w is the noise frequency, and t is time.

Accordingly, in PD controller, the derivative gain amplifies the noise and PID suppresses the noise.

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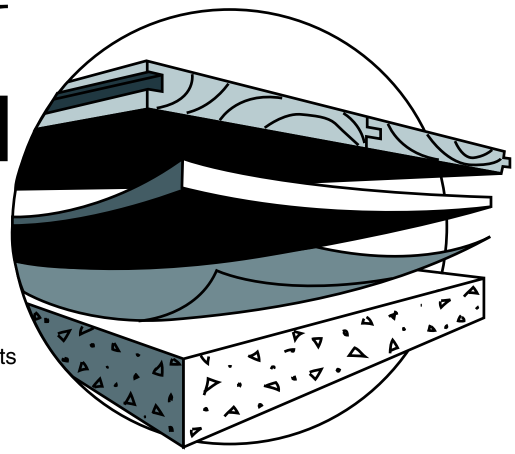
FLOOR ISOLATION



TYPICAL PERFORMANCE CHARACTERISTICS

The table below gives IIC ratings based on tests of various surface treatments Ref. ASTM E989 using an Impactamat resilient interface on a 100mm thick concrete structural floor.

FLOOR SURFACE TREATMENT (Floating Floor Construction)	Impactamat			Overall IIC Rating	IIC Improvement over bare slab	Ref.fig.
	Construction	Type	Thickness			
Loose lay timber veneer flooring with thin foam bedding layer	full cover	750	5mm	47-50	18-20	1
Direct bond 19mm block parquetry	full cover	900	5mm	45-49	18-20	2
Direct bond 10mm ceramic tiles	full cover	750	5mm	44-46	13-15	2
Particle board or strip timber battens supported at nom. 450 x 450 centres with acoustic absorption	pads 75 x 50mm	750	10mm	52-60	21-30	3
Double layer bonded 12mm ply with bonded parquetry, supported at nom. 300 x 300 centres (sports floor)	pads 75 x 50mm	750	10mm	52-57	21-27	4
50mm reinforced concrete slab or 25 mm slab with 20mm bonded marble/slate/ceramic tile	full cover	750	10mm	58-63	27-32	6
50mm reinforced concrete slab	full cover	750	15mm	59-64	28-33	5
100mm reinforced concrete slab	full cover	750	15mm	60-65	29-34	5

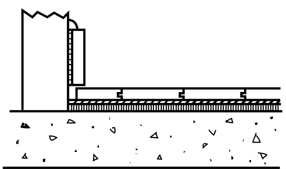


Fig. 1 Timber loose lay floating floor

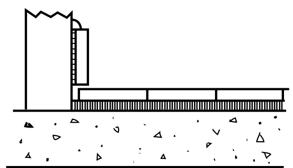


Fig. 2 Direct bond parquetry or ceramic tiles

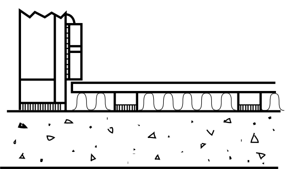


Fig. 3 Timber strip floor on battens with isolated frame wall

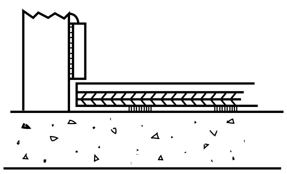


Fig. 4 Sports floor

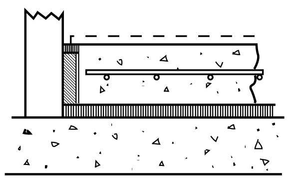


Fig. 5 Concrete slab

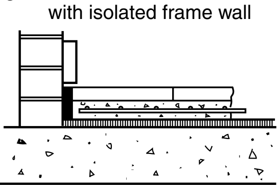


Fig. 6 Marble/slate ceramic tiles with thin reinforced slab

IMPACTAMAT by EMBELTON features two main environmental properties: it is recycled and it reduces noise pollution. Indeed, it is made from 100% recycled natural rubber recovered from tyres, granulated and reconstituted as a solid mat (various sizes are available upon request).

IMPACTAMAT is a flexible material manufactured as a preformed sheet bound together with a flexible binder. It is a low cost impact absorbing layer for covering hard earth or concrete in outdoor applications or as an underlay for in-situ cast or pre-cast concrete floors where noise isolation is required (rubber underlay, acoustic insulation, door mats, playground and sports surfaces, industrial floor tiles etc.).

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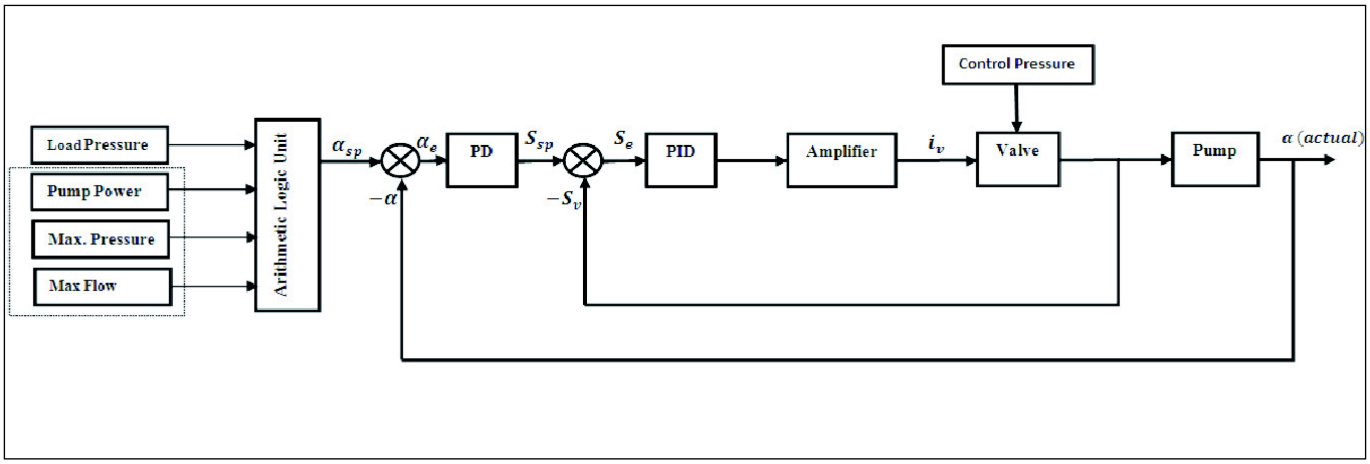

Figure 2: Swash plate pump with double feedback control loop representation

Control Strategies

The current model of the pump comes with a double negative feedback controller.

Figure 2 illustrates the control strategy of a swash plate pump with a double negative feedback control loop. It consists of two loops, an inner loop and an outer loop.

The inner loop controls the position of the moving part with an LVDT position sensor, which senses the position of the spool of the proportional valve, and with a PID controller.

The outer loop controls the pump swiveling angle by using the LVDT position sensor, which senses the position of the swash plate, and the PD controller.

This control strategy has a slow response and it is not convenient for variable applications, where high levels of power shocks and noise are encountered.

Khalil et al [2] proposed a new control strategy to control the pump output by implementing a single feedback loop. They removed the electrical feedback line of the inner loop, and the controller controls only the pump swiveling angle (Figure 3).

They then parameterized the PD controller by using the Ultimate Sensitivity method. The parameters of the PID controller were Kp =1, Ki = 0, Kd = 0.2. Unlike the previous control strategy with double negative feedback, it has less rise time (dropped from 120 ms to 50 ms). However, the pump experienced high levels of vibration and excessive noise, which were not acceptable and must be improved [1].

Chikhalsouk and Bhat, [1] proposed a control strategy with a control strategy with a single feedback PID controller.

This strategy has the same structure as the previous control strategy except that this design has a PID controller instead of the PD controller, and different gains.

Figure 4 illustrates the general structure of the new control strategy. The control variable is the swash plate swiveling angle, i.e. the pump flow rate. The logic unit receives an electrical signal from the pressure sensor, and it computes the specific swiveling angle.

Some values must be considered by the logic unit such as the minimum inclination angle (for pump self-lubrication), the pump power, the maximum pressure and flow. The swiveling angle is compared with the actual swiveling angle, and a certain correction is applied by the PID controller to achieve the required angle.

In [1], Chikhalsouk and Bhat used Ultimate Sensitivity method to tune and parameterize the PID controller and they found that a PID controller with can decrease the rise time and reduce the noise and vibration levels in the hydraulic system.

Experiments are carried out to investigate the levels of the system noise with each strategy (PD and PID).

Experimental Facility

The facility mainly consists of:

1. The hydraulic unit
2. The control unit

The Hydraulic Unit

The hydraulic unit consists of five major parts: a swash plate pump, the secondary pump, a load disturbance unit, oil conditioner, and accessories.

The Swash Plate Pump Arrangement

The arrangement has the pump (1) driven by a 10 H.P. electric motor (2).

The pump changes its swiveling angle by means of a control cylinder (3) mechanically attached to the swash plate.

The proportional valve (4) receives a control signal from the controller to generate the control pressure in the hydraulic lines connected to the control cylinder pushing it.

Three transducers are used to feed the control unit by the hydraulic system inputs, and these transducers provide the load pressure, swash plate inclination angle, and the spool position.

The Arithmetic unit computes the inclination angle according to the load.

The Secondary Pump Unit

A separate hydraulic unit is used to create the control pressure (up to 15 MPa.). This pressure is needed to push the control cylinder (3) through the hydraulic proportional valve (4). The secondary pump (9) is driven by an electric motor (8), which intakes the hydraulic fluid from the tank (10).

In order to maintain the quality of the oil, two mesh strainers are installed. The first mesh (11) is installed on the pump's incoming line, and the second mesh (12) on the by-pass line. The dial gauge displays the value of the delivered pressure (13). An accumulator (14) is

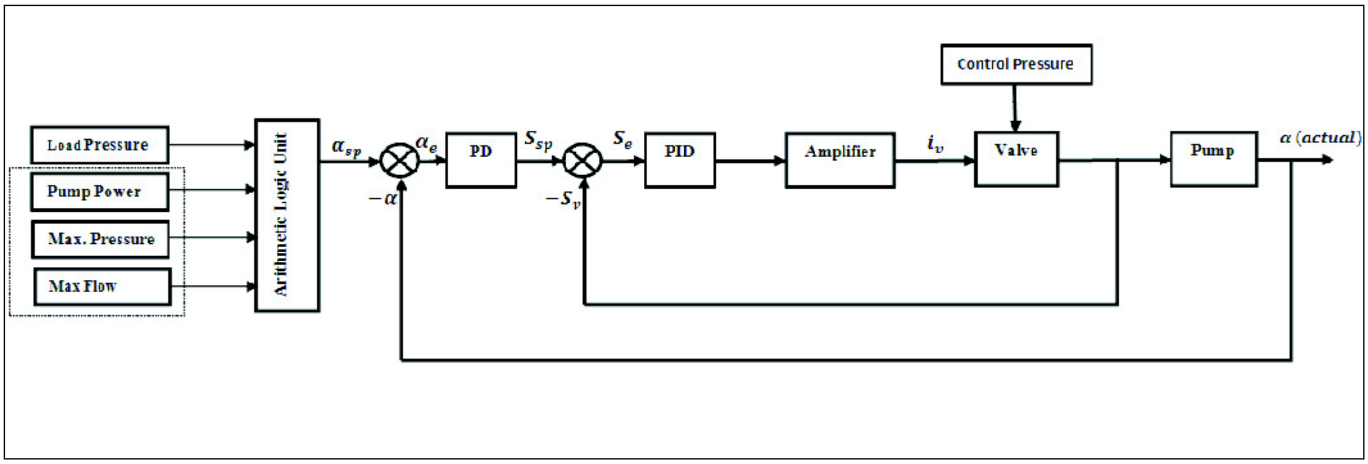

Figure 3: Swash plate pump with double feedback control loop representation

equipped to control the pressure and keep it constant under the different operating conditions, and a relief valve (15) is installed to relieve the excess pressure. An electrical switch is used to operate the pump (17), which is integrated with safety (unloading) valve (16).

Load Disturbance Unit

In order to simulate different operating conditions, a load disturbance unit is added. It has a two-way loading valve (18) that links or cuts off the pump delivery line (31) to the reservoir (10). It also contains a throttle valve (19) to manually tune the loading pressure, and the pressure value is shown on a dial gauge (20). A relief valve (22) is installed to maintain the desired pressure.

Oil Conditioning Unit

Oil contamination and overheating are major problems in hydraulic systems. Certain steps should be taken to keep the oil within its functional specifications. For example, a mesh (23) traps the oil contaminations, and an oil cooler (24) is installed to lower the temperature of the oil so that it remains less than , as recommended. To isolate this unit, two valves are installed (25 and 26). A thermometer (27) is used to measure the oil temperature.

Accessories

An oil breather (28) is installed to eliminate air from the hydraulic system, and cut-off valves (30-33) are added to isolate the swash plate and the secondary pumps and the rest of the hydraulic circuit from the reservoir, eliminating the need to drain the oil tank. A simply supported steel pipe conveys the hydraulic fluid. The specifications of the pipe were as follows: length is 3.5 (m), the inner radius is 0.011 (m), while the outer radius is 0.0127 (m).

The Control Unit

In order to parameterize, build, and test the proposed control schemes and strategies, real time control software is constructed based on SIMULINK 7-1 R.

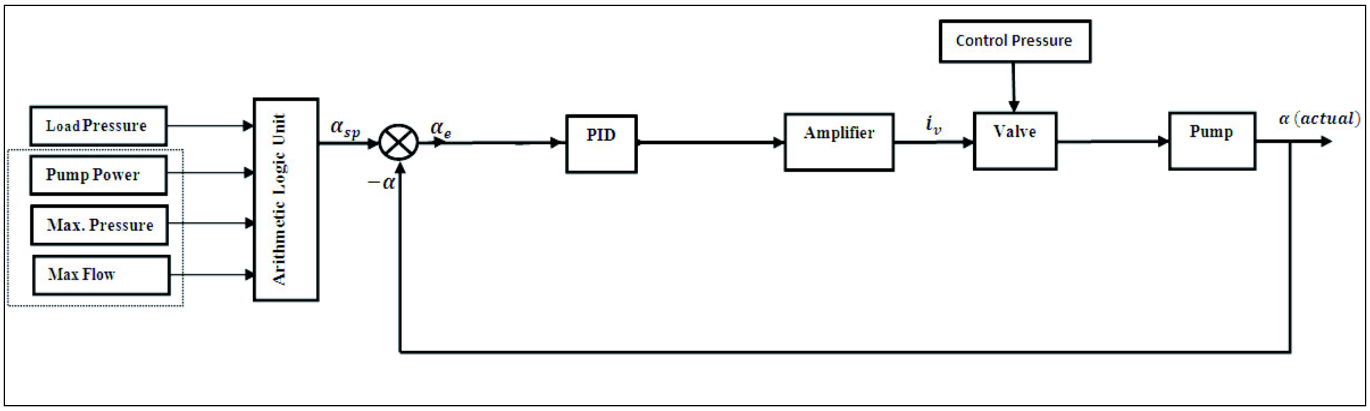

Figure 4: Swash plate pump with single feedback control loop representation (PID controller)

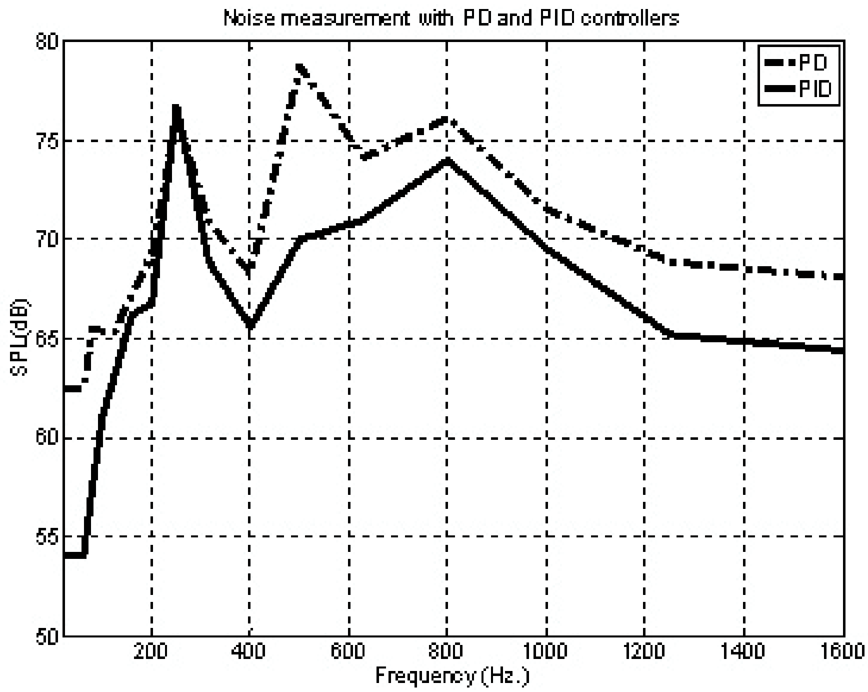

Figure 5: Noise measurement with PD and PID controllers

This consists of a computer connected to an I/O card. The I/O card converts the measured values (voltage values that can be read through the multi-meter) to numerical input and then feeds that to the computer. The computer, with the aid of SIMULINK, generates the required voltage according to the controller's input. The output card reconverts the output of the computer to a voltage and then feeds it to the controller.

The hardware of the control unit includes the following components: An arithmetic logic unit and the PID swash plate controller. These components are built on a green card. The arithmetic unit receives a signal from the pressure transducer and then calculates the required swash plate swivelling angle in the form of voltage. These values are limited by the maximum pump power, pressure, and the flow rate. The control unit is powered by two 12 DC-volt units. Computers process only the analog values, and for this reason LABVIEW software is used to convert the digital signals that are received via the I/O card to analog signals.

Results

The noise levels are investigated for a control strategy with a single PD controller proposed by Khalil et al (2002), where the parameters of the controller are the proportional gain of unity and the derivative gain equals 0. 2. Also, the noise levels of a control strategy with a PID controller proposed by Chikhalsouk and Bhat (2008) are studied. The PID is parameterized to have the following gains: The proportional gain equals1.9, the integral gain equals 8.4 and the derivative gain is equal to 0.01. The measured noise levels are shown in Figure 5.

Figure 5 shows the noise levels measured when the pump is equipped with two different controllers (PD and PID).
It can be noticed that the noise levels decrease by replacing the PD controller by the PID controller, particularly at the higher frequencies. The only exception happens at 270 Hz. where they have the same value regardless of the implemented controller.

Conclusions

Swash plate pump must be equipped with a control strategy to save on the pump power and maintain the pump in good operating condition. The kind of the controller determines the noise generated by the pump, where the current model implements a PD controller which makes the pump noisy. Using a suitable PID controller with the optimum gain reduces the noise significantly.

References

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