Mobilizable Hydraulic Training Bench Design Report

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BREE 495: Design 3

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April 21st, 2020

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Acknowlegement

The project is under the supervision of Professor Viacheslav I. Adamchuk and Professor Chandra Madramootoo. The machine is built for the FMT4 012 Machinery Maintenance course introduced by Mr. Marc-Andre Isabelle in the Farm Management and Technology Program. Technical support: Mr. Scott Manktelow at Macdonald Machine Shop and Mr. René Michaud from Cégep du Vieux Montréal.

Nomenclature

Abbriviation

MAC	Macdonald Campus of McGill University
FMT	Farm Management and Technology
CVM	Cégep de Viexu-Montréal

Executive Summary

This report presents a design of a hydraulic training bench that will fulfill the needs of demonstrating common characteristics This bench could provide the student operation experience on different hydraulic components that are available on the market. Functions and relationship between different hydraulic systems and its various components. The hydraulic training bench has the characteristic of reliable, modular, affordable and environment friendly.

The design is mainly based on an integration platform that can be switched between two common types of hydraulic system; open loop(center) system and closed loop(center) system. This integration platform is powered by a fixed gear pump and a displacement piston pump, the characteristics of the hydraulic system is demonstrated by weight lifting through various directions or electric power generation through hydraulic motors. Varies of logical valves (directional valve, servo valve, etc.) and different piping configurations (two types of quick connect, varies socket and pipe length,) to extend the possibility of training bench to simulate in various working conditions and hydraulic system configurations.

In order to fulfill the needs of quantifying the relationship and characteristics of the testing bench, a meter system that is based on multiple flow meters and pressure meters is deployed to all the major components in the hydraulic system. Pressure release valves are integrated to major pressure points to maximize the security of both client and equipment. Based on the training bench’ s realia nature, a separate pressure alarm system is designed to prevent intended human error, or unexpected pressure surge.

In this report, considerations and assumptions of the system are explained, the choice of hydraulic fluid and filter are developed. Relative standards such as ISO 4406-1999 (ISO, 1999), and safety regulation are concluded. This design could have potential alternation based on client’ s feedback and availability of the components. In generally, this design creates a u nique solution for connecting Farm Management Technology students to real life agriculture hydraulic workload.

Index Terms - Hydraulic training bench, agriculture machinery education

Introduction

Project Aims and Requirement

Hydraulic training bench is widely used in schools to provide certain vocational training or theory demonstration on hydraulic machinery systems. There are several models on the market but the institutions will customise the bench based on their course curriculum and the student needs when they order then bench from industry.

This design of a hydraulic training bench is asked by the FMT as there will be a course open in the 2021 winter semester named as FMT4 012 Machinery Maintenance. McGill's Farm Management Technology (FMT) program is a program that prepares students for the future management and operation in agricultural enterprise.(McGill University, 2019) The FMT students receive a base theoretical introduction for agriculture industrial and skill training. Agricultural machines, most of which utilise hydraulic transmission systems, are commonly seen. Those students need a straightforward illustration to help understand the force, toques and power generation between etc. different hydraulic components systems.

Hence, Mr. Marc-Andre Isabelle, the lecturer of Farm Management and Technology Program finds a need of utilizing hydraulic training bench in his teaching, enhancing the understanding of hydraulic system, also giving students a hands-on experience to explore the behavior and principle the characteristic, functions and behaviour of hydraulic systems and the various component in the hydraulic system (Personal communication, 2019)

The bench has to be installed with the open center and closed center system with some required components: oil tank, pump, pressure relief valve, directional control valve, hydraulic cylinder, hydraulic motor and a return line oil filter. And it is desired to demonstrate the following relationship between hydraulic characteristics: the relation between oil flow and velocity of motion components, between the oil pressure and force & torque generated by motion components; the pressure loss from resistance to flow in the system; the least resistance flow path; the constant flow rate low pressure open center systems; the constant high pressure variable flow rate closed center systems (or load sensing); cavitation in pumps from restrained suction line from clog in line filter, strainer or low oil level.

However, the design should also consider that the FMT students have little background knowledge and the lack of operating experience, as a result, it should be user friendly with well-organised components, visualising of the working principles and a proper safety measures to prevent injuries, contamination and spills. What’s more, this bench will be placed in the ca mpus machine shop which has limited space, so it is expected to be compacted on the provided table frame, mobilize and easy to store. (Marc-Andre, Personal communication, 2019)

The Background

Hydraulic System

Hydraulic system is a machine system that its force is transformed from its applied source (e.g.: A pump) to another point (e.g.: a hydraulic motor or a hydraulic cylinder) by utilising the pressure of incompressible fluid in a sealed system. (Chapple, 2015)

There are a few advantages of this system: The potential performance of the output in a thrust or torque is outstanding in hydraulic system and compared to the same power output, the device using hydraulic transmission system is smaller in size and lighter in weight; the flexibility of the arrangement favors a few user because it is easy to design, manufacture and repair a hydraulic system, so does the installation of the hydraulic component; the operation such as reverse operation, automatic control is easy to be achieved and the adjustment is precise. However, we should also be aware of the disadvantages: the resistance, which could raise the temperature, in the system is high, and the system is sensitive to temperature change because it affects the fluid viscosity so that influence the performance of the system, the ideal working temperature of a hydraulic system is around 54℃, wh at’ s more, around 60% of the energy will be transferred to heat; somehow, the component is expensive because of the precision standard in manufacturing. (René Michaud, CVM, Oral communication, February 19, 2020)

Application in Agriculture Industry

Based on its nature of creating movement or repetition in an efficient and cost-effective ways; hydraulic systems have been applied in the industries where high load is needed such as the automobile industry, aerospace industry, construction work and agriculture industry. Modern agriculture industry depends a lot on machinery systems in cropping activities and livestock management where many big machines are applied.

Different types of implements used for activities such as tillage equipment, combined harvester, trailer and etc. *Figure 1.* is a moldboard plow in Macdonald Farm introduced by BREE 412 Machinery System course lab. This moldboard works for tillage and is used for the heavy clay on the farm in order to make the land to be more productive. This implementation is connected to a tractor which applies hydraulic control to lift up the arm and adjust the angle of the blades. (Martin, Macdonald Farm technician, personal communication, Septembre 30 2019) *Figure 2.* is a tedder used for fluffing the hay on the farm, exposing them to more air, accelerating the drying process and preventing it from getting rotten. The implements are connected to the tractor which applies hydraulic control to lift up or change angle of the arms and adjust the blades’ angles. In the livestock industry, animal sa lt mineral licking block press machine aslo utilises the hydraulic transmission system to compress salt or sawdust of iron, aluminum and brass ,which are usually from recycled materials, into high-density blocks - animial liking salt. The mineral lick is a source of essential mineral supplement to the farm animals.

Figure 1. Moldboard Plow.

Figure 2. Tedder

Hydraulic Lab in Cégep de Vieux-Montréal

Cégep du Vieux-Montréal (CVM) provides students who will practice in industry after cégep study a DEC (diplôme d'études collégiales) program. This program is involved with general study for continued study and professional skill training that satisfies the labor market. (Cégep du Vieux-Montréal, 2019) Among the college and university in Montréal, CVM has the most advanced in use hydraulic lab for students. (Marc-Andre Isabelle, personal communication, 2020)

In the lab, there are various models of hydraulic training benches manufactured by different companies in different years with different components combinations. Mr. René Michaud showed us a recent model in the hydraulic lab manufactured by Vicker’s (the figure on the left), in this model, two pumps and a motor are aligned together to get a better output, the gauges are attached aside on the bench to monitor the temperature and pressure, various kind of hydraulic components are installed on the board. This board provides different models for the same kinds of components, for example, they have 3 models of directional valves grouped together to show the difference between 2 way valves,3 way valves. It demonstrates the hydraulic cylinder power by contracting it to a gas cylinder, and uses a marked plate to show the speed of the motor. This bench could provide the student operating experience on different hydraulic components that are available on the market, it focuses on hand-in experience more than on demonstration.

Pre-existing solution

After searching for models in the market, there are a few in use models including not only the one introduced in the CVM lab, but also benches with just an open centre system or closed centre system. For example, the bench (Figure 2. and Figure 3) manugraturfe by Training System Australia Inc.

Hydraulics Open Circuit Training Bench - SHCO model

Figure 2. Hydraulics Open Circuit Training Bench, Training System Australia Inc.

This training bench emphasizes the reflecting on hydraulic circuits and assembly & disassembly of industrial components by students, and the object of mobile hydraulics. A portion of its component assembly meets our design objective: it is facilitated with hydraulic motor, piston pump with variable cylinder, proportional/ directional control valve. What’ s more, the bench is designed in 3 models in order to change the component kit, which is a gear pump with manual control valve, only piston pump, or directional valve with piston pump. Instead of the traditional ones, the bench is coupled with electric connections and more automotive.

Hydraulics Closed Circuit Training Bench - BHT model

Figure 3.. Hydraulics Closed Circuit Training Bench, Training System Australia Inc

The hydraulic closed circuit training bench is intended for training in mobile hydraulic, indicated by the product webpage, and after comparison, the design and component of this model are more complicated than the previously mentioned SHCO model. The training bench is also equipped with a POCLAIN pump with its calculation by computer, the pressure and temperature sensor measurement the difference in the circutre, what's more, the bench could simulate a resistance force as reality.

Although they are not the model fit in this project, the separated model could provide a clear connection between major components in a single circuit. By reviewing the video posted for those models, we have some general idea on the operation and control.

Analysis

The separation of two systems is not ideal for the storage in the machine shop as the client required, and for convenience, the training bench is expected to be mobile, moving two big objects around the machine shop is not reasonable. The modular systems we found have more ideal outfits compared to the separated sets, standing up-straight and could be two faced.

Figure 4.. The provided working bench

Most of the models are preparing for ordinary automotive training; the training material is not suitable for regular agriculture machinery usage.

Design objectives

In order to effectively fulfill the requirement of the client, this project is determined that the hydraulic training bench is designed specifically for the fulfill the curriculum of the McGill Farm Management, the needs of creating a universally agriculture-related hydraulic training system i s not prioritized. Based on the discussion with our client (Mr. Marc-Andre Isabelle), mentors (Professor Adamchuk, Department of Bioresource Engineering) and technical feasibility with fabricate advisor (Mr. Scott Manktelow), we were able to determine the following list of objectives and range them based on priority from 5 (most important) to 1 (least important).

Based on a series of preliminary investigation, communications and empathizing, following objective has been proposed and agreed on:

- To design a hydraulic training bench that will incorporate both an open loop and closed loop system.

Prioritized level: 5

- To have the components modular, easily interchangeable, the pipe system needs to be assembled easily.

Prioritized level: 4

- To incorporate the proper metering system to indicate pressure and flow rate at various points of the system.

Prioritized level: 5

A need for a proper demonstration interface to link hydraulic machinery performance to real life agriculture tasks.

Prioritized level: 3

To incorporate the proper safety measures to prevent injuries, co ntamination and spills.

Prioritized level: 4

- To utilize components that are common on farm equipment

Prioritized level: 1

After reviewing the previous design works in the Engineering Design 2 course, new design objectives are added on top of existing ones.

- utilizing the old pump

Prioritized level: 5

- Giving easy access for student to use the instrument

Prioritized level: 3

- Pressure readings is assigned as a key measurement to demonstrate the work load of the hydraulic system

Prioritized level: 4

Design Evolution

Design difficulties

In order to form a robust design, the design difficulties of the product need to be identified and targeted. In our case, the design d ifficulties are raised through an engineering design approach that has be en commonly used by material engineers, failure analysis (prevention). Th e objective of the failure analysis is through the process of collecting and analyzing data to determine corrective actions or liability.

Due to the limitation of projects, failure data collection is replaced by consulting our fabricate advisor (Mr. Manktelow) to gather the most frequently happened failure scenario in hydraulic systems. The failure scenario is then processed through backward chaining to clarify the design flaws that cause the problem; then abstracting the design flaws to individual specific design problems. Based on these approaches, the design difficulties are categorized into four different sectors; economic, environmental, ergonomic and safety.

Economic – The quality of hydraulic fluid under harsh working conditions:

A lot of the common problems that caused hydraulic system failure can often stem from contamination of hydraulic fluid（The hydraulic warehouse, 2018) The contamination can be caused through agglomeration and precipitation of particulate contamination, oxidation or hydrolysis of the hydraulic fluids, reactions involving additives and free water. (Reference 4, Hydraulics & Pneumatics) Through consultation, the problem of oxidation, additives reaction and free water is a problem that can be majorly solved by the selection of adequate hydraulic solutions. So, the problem is limited to prevent the agglomeration and precipitation of particulate contamination.

A major reason for agglomeration and precipitation is caused by airborne particulate; the microparticle entering the system through air exch ange from fluid level change in the reservoir. Especially in our design's designated working condition, a workshop with constant wood cutting, metal wielding. These activities release thousands of micro particles creating a greater chance of airborne particulate. Finding the solution of preventing the micro-particles into the system or eliminating the effects on micro-particles is critical for improving the hydraulic fluid quality under the harsh working environment condition.

Environmental - The disposal and leakage handling of the hydraulic fluid

Hydraulics leaks occur from failures at some point in the hydraulic system. A permanently sealed hydraulic system that never springs a leak is unfortunately never to pass. Multiple generations of engineers try to eliminate the hydraulic leaks in their design, still this problem is still the biggest difficulty of the hydraulic design. (Mac hydraulics, 2017) Based on our time, cost, and knowledge limit, it is impractical to have a permanent solution for the leakage, although attempts of using leak-free fittings such as (ISO 16028 interchange coupler) is made to lower the chance of leakage. Since the usage of this hydraulic bench only happened once or twice per year, the cost of hydraulic leak is mainly environmental rather than economic. Our focus turns to eliminating impacts on hydraulic leaks to the environment rather than design a permanent solution for hydraulic leakage.

During our real life practise in component purchasing and building the hydraulic bench we also found that leakage is deeply connected to the use of connectors. Some old style connectors,i.e. NPT connectors do not have specific design for leakage prevention, and usually require a budget in purchasing additional sealing materials like NPT paste. However, some recently designed connectors like O-ring connectors with swirl sealing have a better design of preventing leakage from both flow direction and sideways, in addition, no extra sealing materials are required. Based on our new findings on sealing components and materials, the connection components of some of our key components (directional valve, hydraulic cylinder) are designated to be the ones with O-ring design.

Social and Safety: The prevention on user injury related to irregulated hydraulic pressure

User injury in hydraulic systems are mainly caused by high-pressure hydraulic injection accidents, which is usually caused by a loose connection or defective hose, results in a high-velocity stream of fluid penetrating human skin; causing serious injury, gangrene or even death. In some extreme cases, a minor wound or unseen internal damage could lead to amputation or death due to the toxicity of the hydraulic fluids. Moreover, since the training bench is designed to be operated by FMT students, human error or even intentional damage of the equipment needs to be considered. The emphasizing idea has been implemented to the design, a brainst orm of some common scenarios has been simulated. These questions all summarized to one single challenge, how to regulate hydraulic pressure in the system under normal or even extreme conditions? In which configuration of pressure-maintain components can insure that high-pressure hydraulic injection injury will not happen?

In-Site studies

In February 2020 we also made several visits to CEGEP du Vieux Montreal for having a close look on existing examples of hydraulic benches in their Hydraulics Program, as well as advises and inspirations from the experienced instructors there. In their hydraulic laboratory we saw an astonishing design of integrating open loop and closed loop systems: the gear pump and piston pump are connected in the same axis with the power source. This design greatly reduces the space taken for key components, and keeps its flexibility between the two systems by an easy shifting scheme. The hydraulic bench in CEGEP du Vieux Montreal also has an advanced control system based on computer programs and a sophisticated set of electronic sensors. Due to budget restrictions and concerns about taking apart our old gear pump and reconnecting it, many of the advanced designs from CEGEP hydraulic lab can not be applied to our design. Despite the non-applicable ideas, we learnt many other useful informations from CEGEP, for example, the connection order of each of the hydraulic components, the orientation of male quick connectors and the importance of tank cleaning, which i s crucial to the working fluid quality of the hydraulic system. Also we were advised by Mr. Michoud that the use of electrical generators for hydraulic motor demonstration may lead to electrical accidents, since the problem of short-cuts and grounding are usually overseen by people. In order to reduce risk-management cost as well as save some budget, we took his advice and made changes to our design. Although some of the dsigns need to be re-do, we learnt a minor improvement for our bench that a patterned round plate can be installed on the hydraulic motor for motor speed demonstration.

Figure C.1. Sample hydraulic training system from CEGEP Mont Royal

Figure C.2. Hydraulic piston pump and gear pump from CEGEP Mont Royal

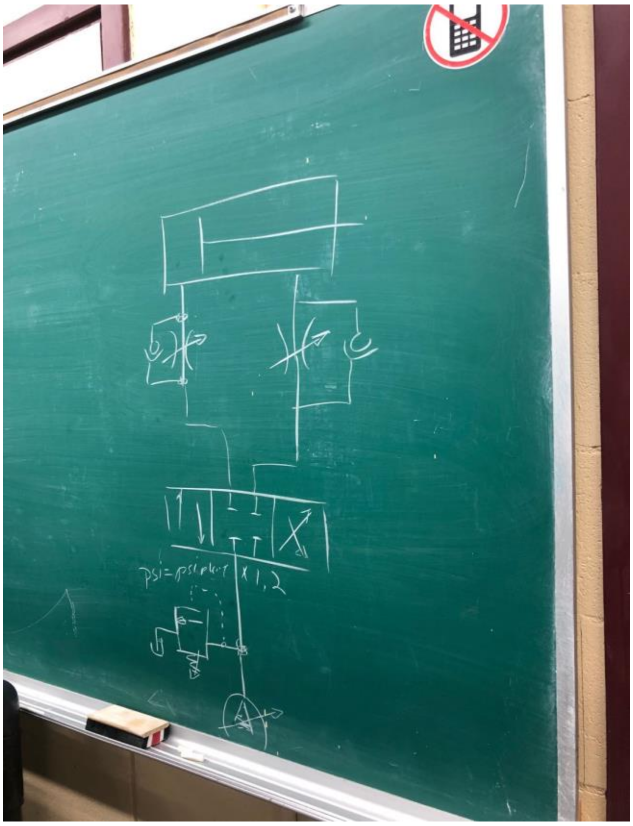


Figure C.3. A sample concept design for the close loop system

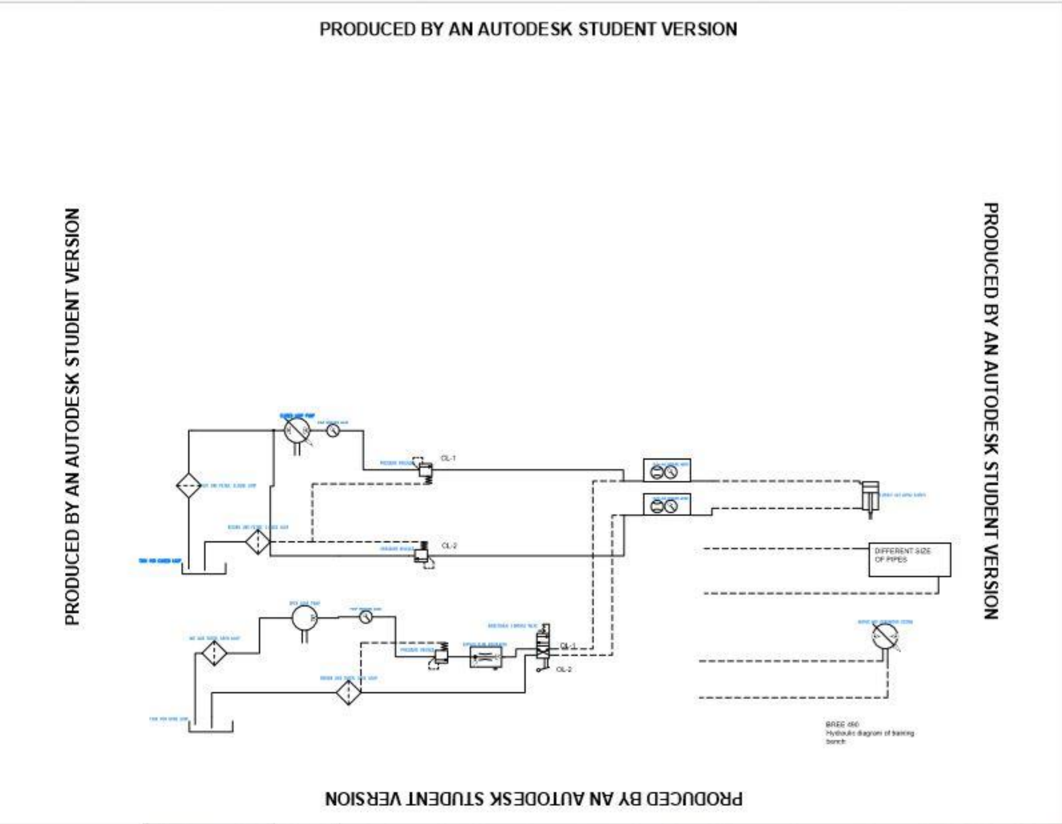


Figure C.4. General design of hydraulic circuit

Preliminary Findings and Design Decisions

Preliminary Findings

Filter System

Three filter systems are considered for the open loop and closed loop systems: Air-line filter, inline & outline filter and kidney loop system. Air-line filters are a popular choice, however, our hydraulic system doesn’t involve any form of independent compressor related component and the moisture level of the operation location is not on our concern. Inlin e & outline filters have a reasonable price, they can both filter the fluid after hydraulic is done, and supply clean fluid for later operations. Kidney loop system is the most effective filtration choice, it is independent to the rest of the hydraulic circuit, and can keep filtering all the time. (Paul, 2016) Based on our hydrologic training bench’s long-life cycle (10 - 15 years), the fluid contamination should be eliminated to the lowest degree. However, based on the reality and circuit limitation, it is impossible to deploy a certain type of the filter on our training bench. Off-line filtration is really attractive to our aspect of design, since it provides the most efficiency and independence with the current deployed hydraulic circuit system. However, due to its low flow rate characteristic, a full cycle filtration will take 1 to 3 hours minimum; which conflicts with our short operation time per used based on our target using scenario (a regular university lab section for assembling, testing and operation). The off-line filtration will lose all its advantage and since it evolves a total isolated hydraulic loop, it surely will increase the installation difficulties for the system. After careful comparisons, inline & outline filters are chosen.

Working Fluids

Decisions are made between industrial fluid and environmentally-friendly fluids. Environmentally friendly fluids are made of a mixture of vegetable oil and animal oil. They will cause minimum damage to the environ ment when they are spilled, and also have a very low toxicity. On the other hand industrial fluid is toxic and needs extreme cautious treatment to avoid permanent damage to soil. In the perspective of economic consideration, use of environmentally friendly oil includes cost of throughout cleaning of the hydraulic system, and additional costs are needed for purchasing components to accommodate working fluid of different specific weight. The cost of industrial oil is reasonable. For safety and environment consideration, if all the components are properly sealed, no harmful fluid will be leaked to the surroundings. Cost of designing a proper seal system will not be greater than the cost of the application of environmentally-friendly oil. Overall speaking, industrial oil is still a suitable choice as a working fluid.

Actuators

Possible actuators for demonstrations of hydraulic systems are discussed. Torque produced by hydraulic forces can be demonstrated by a winch system pulling up weights, or an electric generator producing certain power. Careful consultancy was done with the help of technical advisors and clients. For safety consideration, the output of the generator is adjustable but the start-up torque produced by the hydraulic motor in the winch system is uncontrollable. This will result in an excerpt of sudden force, which is highly likely to damage the whole bench and even lead to terrible accidents. For demonstrating hydraulic pressure in the piston, a decisi on is made between the plan of pressing on an industrial scale and pulling up a certain weight with a pulley system. The similar safety issue comes up at the start up phase of the piston system, a sudden increase of pressure will damage the structure of industrial scale, which will make the scale a one-use component. In the end, the plan of using generators for hydraulic motors and using pulley systems for hydraulic systems is accepted.

Design Decisions

In the theoretical design of hydraulic bench in Design 2, we denied the design of pulley system and mechanical press system due to safety consideration and the short product life of the components. Therefore, a lever system using hydraulic cylinders and a generator system driven by a hydraulic motor are being considered.

After receiving the advice from Mr. Michaud in CVM, the electric generator design was also rejected due to safety considerations. Then Two new options were brought forward: Hydraulic Dynamometer and Agricultural Conveyor.

For Hydraulic Dynamometers, they are fancy options for demonstrating hydraulic torque, but the price issue and their large volume kept us from picking it. Agricultural conveyors could be another affordable choice, however, they are still too bulky and their demonstration of various torq ue produced by hydraulic motors is not as good as expected. Therefore both of the ideas were rejected.

Later we were hit by the idea of a prony brake. This is a preliminary kind of dynamometer that uses a friction block to clamp the rotating axis of a motor and measure its torque. Various weights can be added to one end of the brake's arm, and as the brake got tightened, friction torque produced by the brake will be balanced with the original torque of the motor.(Encyclopedia Britannica, 2019) The primary advantage of prony brake is its simplicity, it can be easily built under the current condition of the workshop, and it can also be easily operated by two or three people. For safety considerations, as long as the output of the motor is controlled in a reasonable amount, the risk level of the prony brake is essentially lower than the electric generator. The summation of economy, easy access and safety made the prony brake a final choice for hydraulic torque demonstration.

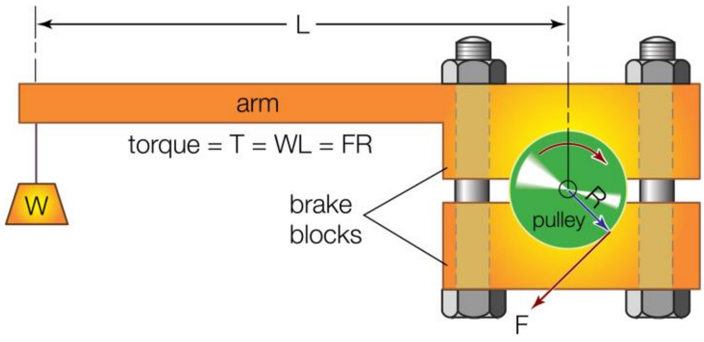


Figure A.1. An illustration of the pony break

Design concept and example calculations

For our design concept, our working bench builds on a wheeled bench with a metal plate installed on the back. The key components (piston pump, tank, prony brake, hydraulic motor) are installed on the center and lower part of the bench as weight anchors, while the valve and gauge components are fixed on the metal wall at a suitable height (about 60 cm from the bench surface) for operation and demonstrations.

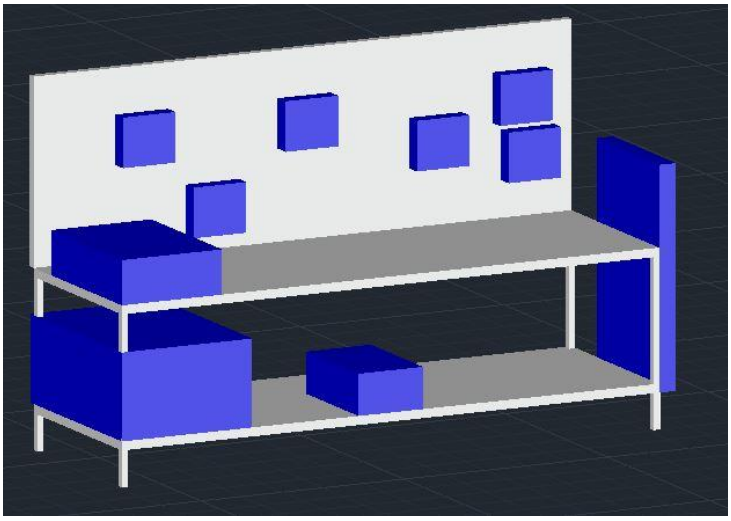


Figure A.2. A conception design for the training bench

For the hydraulic actuators, a hydraulic lever is installed on the right side of the bench with its arm folded up when the bench is not in use. The prony brake is installed on the left bench surface for a close-up demonstration purpose. For the lever, the hydraulic cylinder can be installed both above the arm and below the arm for demonstrating different working scenarios, and when the lever is loaded with a mass while the cylinder is not pressurized, the far end of the arm will perfectly rest on the ground due to its length, preventing mechanical damage. The prony brake is installed on the bench surface, since a long arm is used for the brake, a stopper was installed near the far end of the arm to restrain any sudden movement made by motor' s accidents.

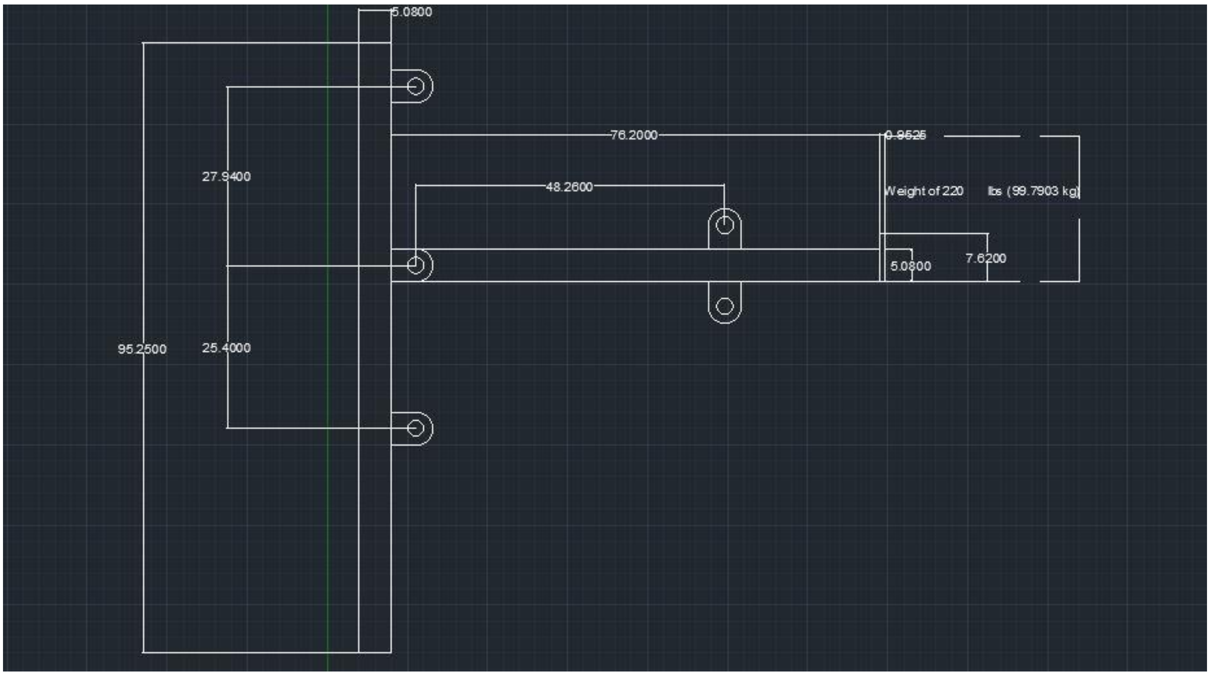


Figure A.3. Detail design of the weight-lifting lever system

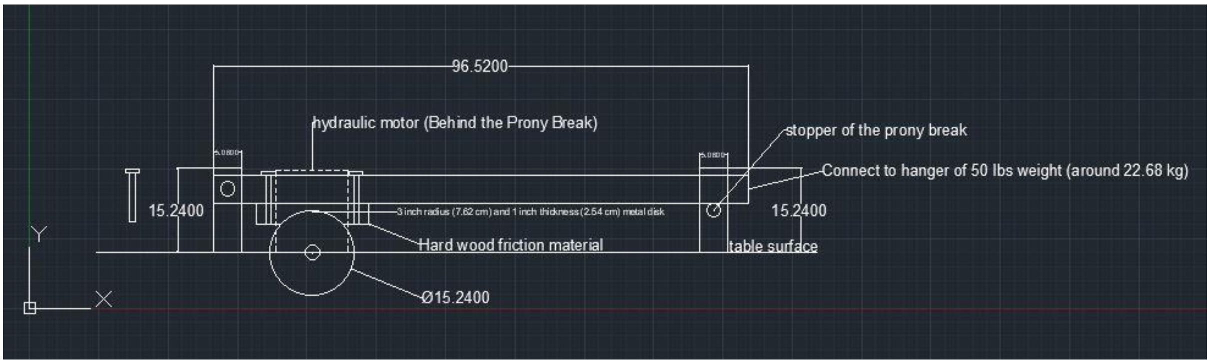


Figure A.4. Detail design of the pony break

For the hydraulic cylinder, given its piston area as 8.39 sqin (0.005413 m), and when a 220 lb (99.79 kg) weight is applied at the end of the lever, and the density of lever arm is 4.33 lbs/in (77.33 kg/m) the pressure generated inside the cylinder will be:

F = (220*30*sin(1.026 rad)+0.5*30*sin(1.026 rad)*4.33*30)/(19*sin(0.6 rad))

= 476.46 lbs (2120.25 N)

Therefore,

P = F/A = 476.46 / 8.39 = 88.97 psi (613.43 kPa)

For the prony brake, assume the motor is producing a torque of 360 lbs-in (40.67 N*m) and driving a 3-inch (0.0762 m) radius metal plate and the brake's arm is 36 inch (0.91 m), friction coefficient of the material is 0.3 and a mass of 50 lbs (22.68 kg) is attached on the other end of the brake. The counter torque will be:

Torque = 50 * (36/5) * 0.3 * 3 = 324 lbs-in (36.61 N*m)

This is a torque approximately counter balances the torque generated by the motor.

Challenges

There were some challenges waiting to be overcome during the design progress. First, time management was the biggest challenge during the project, arranging meeting between the team, Mr.Isabelle and Mr. Manktelow was not easy, as they were both busy for their own work, the meeting time had to be fit for the schedule for 5 persons, besides, most of the hard work has to be done under the supervision of technician Mr. Manktelow in the machine shop on campus, the following solidworks were expected to be done during the time when both of the machine shop and Mr. Manktelow are free. Second, language barrier is another major issue affected the progress, during the communication with our supplier Pièces Hydrauliques Ménard Inc (Les) and the Cégep du Vieux-Montréal, a certain level of French skill was needed, especially when communicated with the supplier, we could only talk to the manager, Mario, as he is the only bilingual staff. The last challenge is the COVID-19 outbreak, school work had to be cancelled due to this, the installation and assembling were stopped, which is unpredictable and uncontrollable.

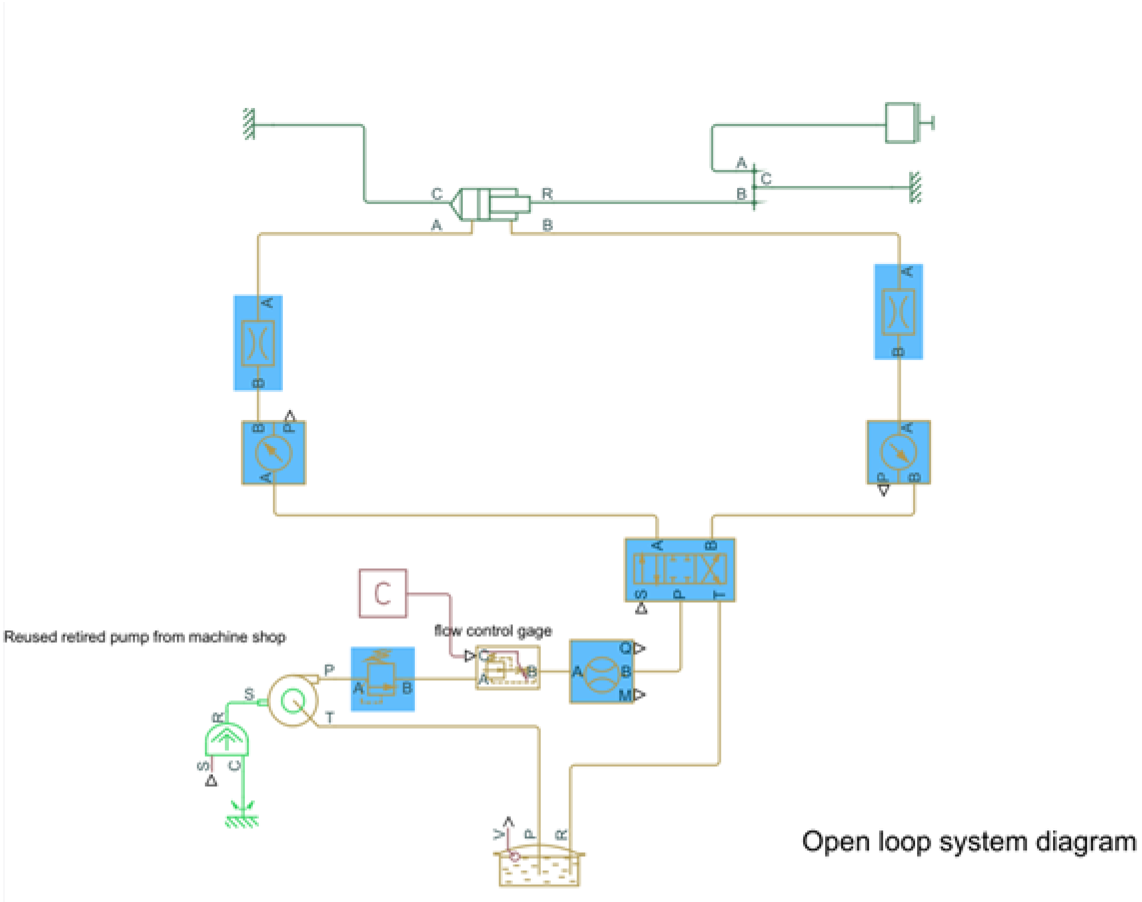
Final design and components choice

The final design of the hydraulic training bench has been divided into two major subsystems (open loop sub-system, close loop sub-system) based on its teaching scenario. Since both subsystems will not run at the same time, some components are sharing through both subsystems.

Based on our teaching target and implementing the idea of prompting hydraulic knowledge through hands on experience. The training bench distinguishes itself from market solutions through requiring the whole system be self-assembled and troubleshooted by students themselves rather than manufacture. Base on that, all the fitting is being converted to the general purpose quick-action hydraulic couplers (ISO 5675:2008, DIN)

Open loop sub-system

The open loop sub-system is in charge of demonstrating pressure difference of the open loop hydraulic system under various different loads; and different hydraulic cylinders' performance under the same power source. To achieve that, an iconic open loop hydraulic system and a compacted lever-based weightlifting system is built to fulfil the demonstration requirement. Also, in order to make it relevant to the daily agriculture machinery operation, a mechanical failure scenario could be simulated through the embedded choke valve.



(*Highlighted parts are sharing components between two subsystems*)

<u>Fig. F-1 The open loop subsystem final design</u>

Based on the economical and availability, the following list of components is used in this open loop system.

<u>Table. F-1 Component detail of the open loop subsystem</u>

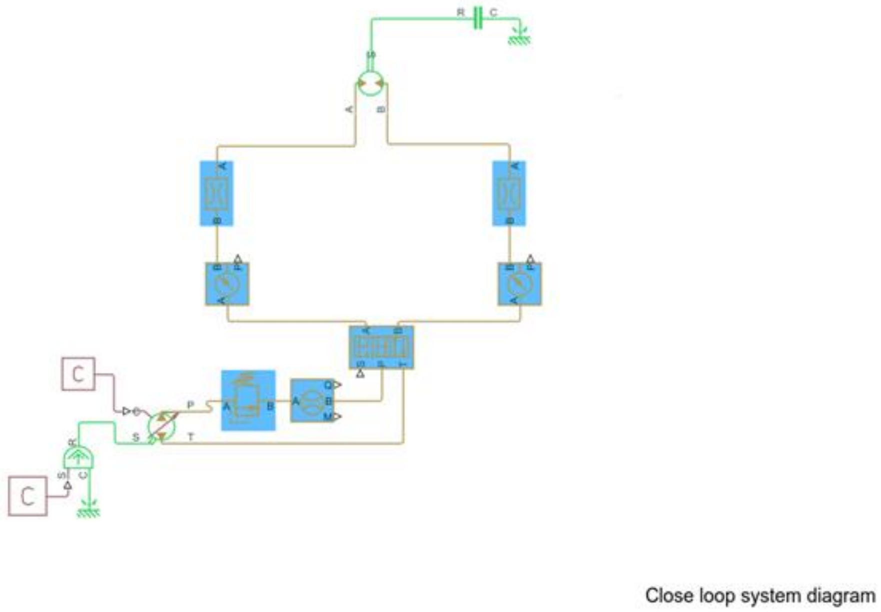
Components name	Components model number	Using in both sub-system

Hydraulic cylinder 1	CUSTOM® TR2.5-2008	N
Hydraulic cylinder 2	CUSTOM® TR2.5-3508	N
Directional valve	PRINCE® RD2575-T4-ESA1	Y
Flow control valve	PRINCE® WFC-600	N
Flow meter	LENZE® SSF-L0005-N08	Y
Pressure relief valve	DELTA POWER® DE-EWA-00-3000	Y
Pressure relief valve - Mount	DELTA POWER® 30102364	Y
Filter	LENZE® CP 380	N

(Tubing and fitting are not concluded)

Close loop sub-system

Rather than illustrating hydraulic system’s pressure change under the various loads, the close loop system is designed to demonstrate the performance change through altering the pressure of the hydraulic system. To achieve that, a home-made pony break is built to quantify the system performance of the hydraulic system. Also, a choke valve is added to simulate a machine failure scenario.



(*Highlighted parts are sharing components between two subsystems*)

<u>Fig. F-3 The close loop subsystem final design</u>

Bae on the economical and availability, the following list of components is used in this closed loop system.

Table. F-2 Component detail of the close loop subsystem

Components name	Components model number	Using in both sub-system
Piston pump	MENARD® 1018D31RPKCE8N00	N
reservoir	VERTICAL NON-J.I.C TV-175	N
Directional valve	PRINCE® RD2575-T4-ESA1	Y
Flow meter	LENZE® SSF-L0005-N08	Y
Pressure relief valve	DELTA POWER® DE-EWA-00-3000	Y
Pressure relief valve - Mount	DELTA POWER® 30102364	Y
Motor	CUSTOM® BM1 313-0390	N

(Tubing and fitting are not concluded)

Highlights of the selection components

Open loop circuit is the most common circuit on the low to mid end agriculture machinery. It generally has the nature of easy maintenance and diagnostic. The circuit distinguishes itself by letting its return flow directly to the reservoir rather than through the pump. (Islam, Raghuwanshi and Singh, 2008) An adequate volume for the reservoir, pressure relief valve setting could protect the fluid from overheating. And a well selected suction and return filter to keep the cleanness of the circulating hydraulic fluid.

Reservoir capacity verification

For our hydraulic training bench, each sub-system has its own reservoir; due to the fact that the old pump that we recycled from the machine shop already has a built in reservoir in it; and all the temptation of integrating this reservoir to the close loop system resulting unsatisfied results.

Although it is safe to say that the pump's built-in reservoir should meet the pumps operation requirement; however, based on the working condition and the load of the system, the temperature of the hydraulic fluid will drastically change. In order to build a reliable system, a verification of reservoir capacity is needed.

For the verification, a Simulink™ Simscape hydraulic system simulation is set. The whole simulation, a fix-placement gear pump will be used as the major power source of the system. All the configuration of the system has been imported from our components' catalog menu, the reservoir volume will be simulated and compared with the reservoir from the recycled machine shop pump. A maximum load of 452.23 kg was tested on the closed loop system, with all two cylinders run on tested. (TR2.5-3508 and TR2.5-2008)

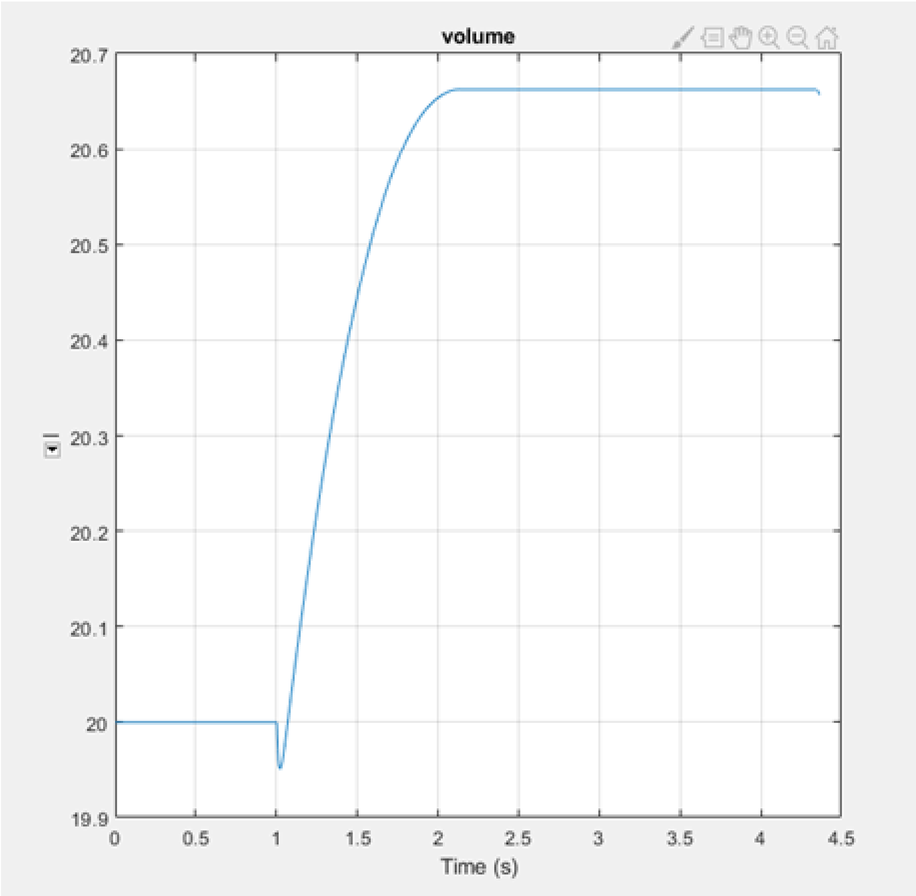


Fig. F-2 The open loop reservoir simulation results

The simulation results in a maximum reservoir volume demand under the maximum load 452.23 kg with the TR2.5-3508 cylinder. As the Fig.F-2 illustrates, the system reaches the maximum reservoir volume after the cylinder is fully extended under the load (after 2 seconds). Based on the name of the recycled pump, we identified that the built-in pump has a 30L reservoir which is enough for our circuit under the most extreme circumstances.

The selection on suction and return line filter

Elimination of contamination on hydraulic fluid systems is a priority of hydraulic system designs. Generally, common filter types in hydraulic system are:

Table. F-2 Characteristic of the common types of hydraulic filter

Filter type	Common function
Suction filter (strainers)	Protect pump for large, damaging contamination, pipe debris
Return-line filters	Protect tank from the part wear
Pressure line filters	Filling low contamination tolerance for servo directional valve
Off-line filtration	An independent oil filtration system targeting for high cleanliness level
Air-line filters	Trap debris in air lines to protect downstream hydraulic components

Based on our analysis at the *Premilitary finding* section, pressure line filter, off-line filter and air-line filter is not applicable for our design. The filtration system of the open loop system will be consisting of one suction filter and one return line filter.

A spin-on type of filter has been chosen for both the suction filter and the return line filter. Base on other common types of suction filters require mount or other supported structure on the pump, and any modification on pump could result in extra work and potential safety hazard. Furthermore, since the spin-on type filter is the commonly used type of filter in the tractor, using this specific type of tractor could bring real life hydraulic knowledge closed to the FMT students. Not only did the spin-on type filter work well on the suction filter, it also can be used as a return-line filter, based on its versatility and high degree of freedoms.

For the specific chrematistic of the spin-on filters, a proposal of using both identical filters for suction and return-line filter was proposed on the preliminary design stage. However, based on detailed research, the suction filter and the return-line filter are targeting different kinds of contamination in the hydraulic system. Suction filters are more common on filtering contamination above 75 microns; whereas, the return-line filter is more focused on contamination around 3 to 25 microns. (Hydraulics & Pneumatics, 2008a) Using an inappropriate filter (using a finer filter for our case) on the suction line could lead to increased pressure in the syste m, causing hydraulic fluid overheating and creating high pressure points on the system; potentially causing catastrophic failure, such as pipe burst.(Hydraulics & Pneumatics, 2008b)

After considering the economic and part availability; CP380-1018, a variant of LENZE® CP 380 with a target contamination size of 10 micron is used for return-line filtration. Where as CP380-4018 were used for the suction filtration, targeting contamination above 40 microns.

Consideration on cylinder selection

There are a vast variety of hydraulic cylinders in the market, types like: single acting cylinders, double acting cylinders, welded rod cylinders and telescopic cylinders. Based on the nature of our design involved in constant assembly and disassembly, a welled rod cylinder is excluded for our consideration. Telescopic cylinders can be an interesting components to add into the system; however, a telescopic cylinder involves in a sets of single acting and double acting cylinder with different diameter; which is hard for the student to quantified the difference on the hydraulic fluid pressure when different diameter of cylinder is used in the system. (Desk, 2019) Hence, our final solution is between the single acting cylinders, double acting cylinders and tie-rod cylinders.

During our market research, tie-rod cylinder is widely used in the industry and manufacturing application; this includes agriculture used.

The ease of maintenance, repair and assembling, and its fluid leakage prevention feature based on its end caps design has made it our best candidate over the single and multiple acting cylinder. After making a few estimation and calculation to simulate the cylinder’s integration with our lever based weightlifting system, the detail of our chosen tie-rod cylinder is as following:

Table. F-2 Detail of selected tie-rod cylinder

Cylinder model	Maximum working pressure	Column loads at the maximum working pressure
TR 2.5-2008	2500 PSI	3562 kg
TR 2.5-3508	2500 PSI	10910 kg

Motor selection:

For agriculture equipment, a motor is an essential component for any application with rotary movement. The motor for the agriculture equipment tends to be having a characteristic of “low-speed, high torque”. In this kind of usage scenario, a greater amount of torque is needed at the start up from the stationary position, making the required torque higher than a typical gear pump’ s maximum load. Hence, two rotor assembly design, gerotor and roller gerotor is used to overcome this difficulty.

Both gerotor and roller gerotor are designed to use the oil forces of the rotor to turn within the stator converting fluid power into rotary power, then resulting in providing torques. Whereas gerotor uses the stator’ s wall to convert the fluid power; roller gerotor incorporates roller pins to form the displacement chamber, a place for fluid power conversation. (Fabiani et al., 1999)

Since the roller eliminates the gaps of the gerotor design and creates a tighter fit and tighter tolerance to all the inside components. It makes less oil to pass through to force the gear harder, ultimately bringing more torque. After a series of research, we believe that a roller gerotor design is more robust, lasts longer and performs better. Hence, based on the availability, the CUSTOM® BM1 313-0390 was chosen for the project.

<u>Table. F-3 Detail of selected motor</u>

Flow (GPM)	Speed (RPM)	Pressure (PSI)	TORQUE (IN-LBS)
15	1350	2030	734

Conclusions

Hydraulic working bench has been available on the market for a while, with different designs and variations, it provides the user a demonstration or in hand exercise experience. The custom will choose components or design models based on their own needs, and customisation also depends on the budget. Most of the models applied in vocational training are very intuitive as the targeted users are, as the students in CVM DEC program said, prepared for industry workers who need to know more about device operations than on theoretical research and calculation. The clients of our product are Mr. Marc-Andre Isabelle and the students in FMT who register course FMT4 012.

This project design prepares an hydraulic training bench integrating both closed loop system and open loop system, and demonstrates how hydraulics is used in agricultural machinery. Based on the knowledge and experience gained by in-site investigation in CVM, market research online and visiting local hydraulic company Pièces Hydrauliques Ménard Inc (Les) We finally came up with the idea that fits the FMT’ s need. Our design is tailoring a hydraulic training bench for FMT program that integrates both open loop system and closed loop system into one bench, uses market available hydraulic components and focuses on agricultural related hydraulic demonstrations. The bench is small in size, also mobile for better storing in our faculty machine shop. After we considered and compared several combinations of components based on the in-site visit in CVM, he consultation with Mr. René Michaud, budget and reducing waste to the environment, and our working pressure, we only chose several easy-to-operate and commonly seen products that were enough to fulfill the need of the course, and decided to reuse the old hydraulic pump in the shop.

To conclude, our hydraulic demonstration bench utilized a hydraulic cylinder and hydraulic motor to demonstrate the work of hydraulic pressure by doing lifting and counter torque. These two demonstrations are strongly connected to real-life agricultural work as material lifting and work of tractors. The accessibility and straight-forward interface is also tailored for first-year FMT students.

Comparison

1) **Comparison between junior design project and senior design project:**

   Before Design 2 and Design 3, a fundamental Design 1 course had been introduced to the junior Bioresource Students. The project in Des ign 1 lasts shorter, more fundamental, and less flexible. It briefly introduces what an engineering project looks like. However, the standard is higher in the current project runs through Design 2 and Design 3. It involves communication outside the team, and less dependent on the course instructor. Although the degree of freedom is high, the theoretical knowledge base and project evaluation methods are much stronger than the previous one.

2) **Comparison between the audience of our design and the bench in CVM**: the students in CVM who are trained on these hydraulic devices are studying in mechanical engineering DEC program, after the training, most of them will work as techniciens in the related industry in which various hydraulic machines apply. Due to this situation, they will have more background knowledge on how hydraulic systems work with a series of theory courses, problem solving based on real industry situations, and in-hand experience on different models of components, motors, pumps that existed in the mechanical industry. In contrast, FMT students focus more on farming knowledge and skills, agricultural machines that utilise hydraulic transmission are only part of their course and career. The knowledge base on mechanical theory, mathematics and physics courses is weaker and the variety of hydrauliced they will face is much less than that of the CVM students. The purpose of demonstrating the working principle in hydrau

lic systems weighs more than that of in-hand skill training. Instead of installing a complex hydraulic system with a big amount of hydraulic components, we have to focus more on how to visualise the work done by the hydraulic system.

Evaluation Conclusion

Required by our client, the bench we design installed with both open loop and closed loop. Before the cancel of school happened because of the COVID-19 outbreak started, the following design has been confirmed with Mr. Marc-Andre Isabelle. The pump of open loop and the one of close loop will be attached to the oil tank and their own motor, later the power system will be connected to the component mounted on the steel board with pipes that will coupling connectors on each side, the components that will use coupling connector are directional valve, flow control valve, flow meter, pressure gauge, pressure relief valve. The cylinder will attach at the side of the bench.

There are a few tasks remained, 1) the parameter of the pump used for open loop remains unknown, as the pump is there for decades, the hand book for it is lost, however this pump was in use for other work in the workshop, Mr. Scott Manktelow didn’t allow us to disassemble it to find the plate until we finished all other parts. 2) The steel board has not been drilled and components not mounted, so we don’t know if the arrangeme nt is user friendly for connection and operation (lining and height).3) the workshop of cutting pipe and mounting connector in company Pièces Hydrauliques Ménard Inc (Les) had been cancelled 4) the method to demonstration of torque are still under discuss as we failed a few plan with Mr. Marc-Andre Isabelle and we have to stop the work due to school being cancelled 5) all of the existing data are based on computing with theoretical and ideal conditions, no actual tests could be done as the built-up process stopped for COVID-19 outbreak.

This project involves the process of applying scientific theory on solving real life problems, a design not just based on school knowledge and team cooperation, but also connected to communication with different roles in the society.Mr. Michaud and the visit of CVM gave a huge impact on this project, showing the transition between our study and vocational training application, communicating with suppliers, getting quotations, etc. are what we could not get from the textbook. The unexpected situation of the COVID-19 outbreak stopped the project, however, we wondered if we could continue on this built-up process when school life becomes normal. Our team will keep in touch with our technician support and client on this project, hopefully we could see the finalised product.

Reference:

ISO. (1999). ISO 4406:1999: Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles. Geneva, Switzerland:ISO

ISO. (2008). ISO 5675:2008: Agricultural tractors and machinery – General purpose quick-action hydraulic couplers. Geneva, Switzerland:ISO

Chapple P. (2015). Principles of hydraulic systems design. New York, NY: Momentum Press

McGill University. (2019). Farm Management and Technology – McGill University. Agriculture and environment sciences. Saint-Anne-de-Bellevue. Available at: https://www.mcgill.ca/fmt/. Accessed 29 November 29, 2019.

Islam, A., Raghuwanshi, N. S., & Singh, R. (2008). Development and application of hydraulic simulation model for irrigation canal network. Journal of irrigation and drainage engineering, 134(1), 49-59.

Hydraulics & Pneumatics. (2008) Book2, Chapter 9: Filtration. ENDEAVOR Business media: Nashville, TN. Available at: https://www.hydraulicspneumatics.com/technologies/other-technologies/article/21884322/book-2-chapter-9-filtration

Desk, W. (2019) 5 Types of Hydraulic Cylinder. Worldwide Hydraulic Professionals. MARBOROX INFOMEDIA:India. Available at: https://whyps.com/5-Types-hydraulic-cylinder

The hydraulic warehouse. (2018). The facts about Hydraulic Fluid and Hydraulic System Failure. Seven Hills, Australia. Available at: https://www.thehydraulicwarehouse.com.au/the-facts-about-hydraulic-fluid-and-hydraulic-system-failure/. Accessed November 29, 2019.

MAC hydraulics. (2017). The dangers of hydraulic leaks. Brookhaven, PA. Available at: https://mac-hyd.com/blog/dangers-hydraulic-leaks/. Accessed November 29, 2019.

Fabiani, M., Mancò, S., Nervegna, N., Rundo, M., Armenio, G., Pachetti, C., & Trichilo, R. (1999). Modelling and simulation of gerotor gearing in lubricating oil pumps (No. 1999-01-0626). SAE Technical Paper.

Marougy Thelma. 2012. Hydraulic fluids can help you go "green". Hydraulics & Pneumatics. London, England and Wales. Available at: https://www.hydraulicspneumatics.com/. Accessed 24 November 2019.

Heney Paul. 2016. What are kidney loop systems?. Sealing & Contamination Control Tips. Cleveland OH. Available at: https://www.sealingandcontaminationtips.com/kidney-loop-systems/. Accessed 24 November 2019.

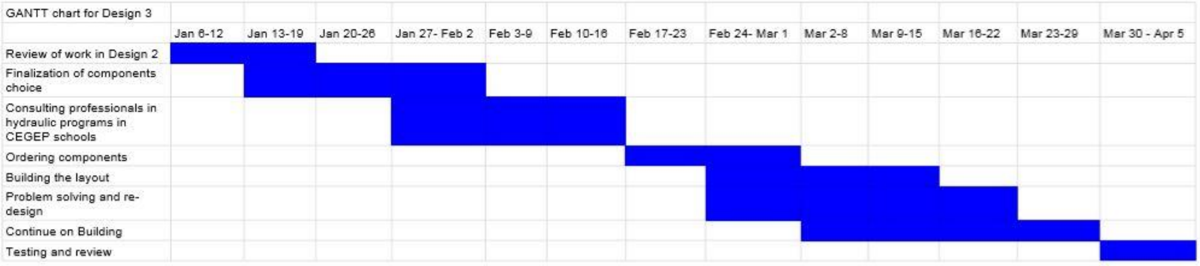
R.E. Cantley. "The Effect of Water in Lubricating Oil on Bearing Fatigue Life." ASLE Transactions, American Society of Lubrication Engineers, Volume 20, No. 3, p. 244-248, 1977; from a presentation at the 31st Annual ASLE Meeting, Philadelphia, Penn.

Dynamometer | measurement instrument. (2020). Encyclopedia Britannica. Retrieved 21 April 2020, from https://www.britannica.com/technology/dynamometer

Standard Belt Conveyors | Patz. (2020). Patzcorp.com. Retrieved 21 April 2020, from https://patzcorp.com/products/agriculture-products/conveyors-and-feeders/belt-conveyors/standard-belt-conveyors/

Hydraulic dynamometer, water brake | POWERLINK. (2018). POWERLINK. Retrieved 21 April 2020, from https://www.powerlinkpt.com/hydraulic-dynamometer-en/

Appendex:


GANTT chart for Design 3
Jan 6-12
Jan 13-19
Jan 20-26
Jan 27- Feb 2
Feb 3-9
Feb 10-16
Feb 17-23
Feb 24- Mar 1
Mar 2-8
Mar 9-15
Mar 16-22
Mar 23-29
Mar 30 - Apr 5
Review of work in Design 2
Finalization of components choice
Consulting professionals in hydraulic programs in CEGEP schools
Ordering components
Building the layout
Problem solving and re-design
Continue on Building
Testing and review