

REHAB *T e c h*

Monash Rehabilitation Technology Research Unit



Motorised Overhead Harness

Andrew Searle



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REHAB Tech- Monash Rehabilitation Technology Research Unit

C/- C.G.M.C.

260 - 294 Kooyong Road

CAULFIELD VIC 3162

AUSTRALIA

Email rehab.tech@eng.monash.edu.au

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INTRODUCTION

The outline for this project was to construct a system which will operate in conjunction with the walkway already in place in the biomechanics lab, to give users assistance in walking. It will hopefully aid patients in improving their gait, particularly in periods of rehabilitation, such as recovering from a stroke or recent lower limb amputation. There are three key areas that the final system should address, and these are

- **SAFETY**

The user should be confident that they will not be able to fall or trip and thus injure themselves. Once the patient has confidence that the harness will prevent this they will be able to direct more attention to walking technique rather than being concerned about their stability and balance.

- **WALKING**

The system must enable the patient to walk as normally as possible yet still be supported by the harness, so that the users gait is improved under as normal as possible conditions.

- **WEIGHTBEARING**

The harness arrangement should also be capable of relieving a portion of the patients weight from their legs. This is extremely beneficial when the patients leg strength is less than that required to walk unaided, or pain from pressure points on the legs hinders the patients gait development.

PRELIMINARY IDEAS

The first decisions were made to the effect that the harness would operate by means of a rail connected to the ceiling and carriage/s running on this. The project can thus be separate into the following key constructional areas:

RAILING
MOTORISATION
WEIGHT RELIEF
CONTROL

RAILING:

The most important criteria for the rail and carriages was that they should be as lightweight as possible, smooth running, easy to install and capable of the required load rating. Another point that must be kept in mind is the length of rail that can be

transported up to Rehab tech is limited by the size of the lift and/or stairwell. The longest length that can easily be used will be around 6m. (using the stairwell for access.)

Various options were examined for the railings. The resulting problem with most systems was that even if the rails could be found to carry the desired load, the matching carriages could not, or carriages did not exist at all. It is possible for carriages to be made at Rehab tech, but it would be beneficial and probably more cost effective to find an inclusive rail and carriage system to use.

The desired load (assuming a person falls onto the harness with their whole body weight) was set to be around 1000kg. This is roughly double the expected impulse of a falling person but in a system such as this a large safety margin is not unwise.

Some rails considered were:

I - Beam - Many sizes and strengths available, also easy to fix to concrete beams in the ceiling. Unfortunately carriages are not easy to find and those available are very heavy duty and thus do not run easily. May not be the best option when considering how to propel the carriage either.



Suppliers: GIS cranes, Steel merchants.

J - Beam - Similar advantages and problems to I - Beam, but no carriages are available at all. Any carriage constructed may have difficulties in that it may overbalance or slip off side.



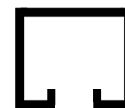
Suppliers: Steel merchants.

Circular Tube - This system offered promising possibilities. Simple design, clean and smooth running. This would also allow some rotation from side to side as the patient was walking. Although (according to the manufacturer) the carriages were capable of holding over 2000kg, the rails were structurally weaker and were only rated to around 350kg, thus not suitable to our purposes. (Note, however that these rails are used in playground equipment and thus suited to smaller people falling heavily onto the carriage)



Suppliers: Bomac Engineering.

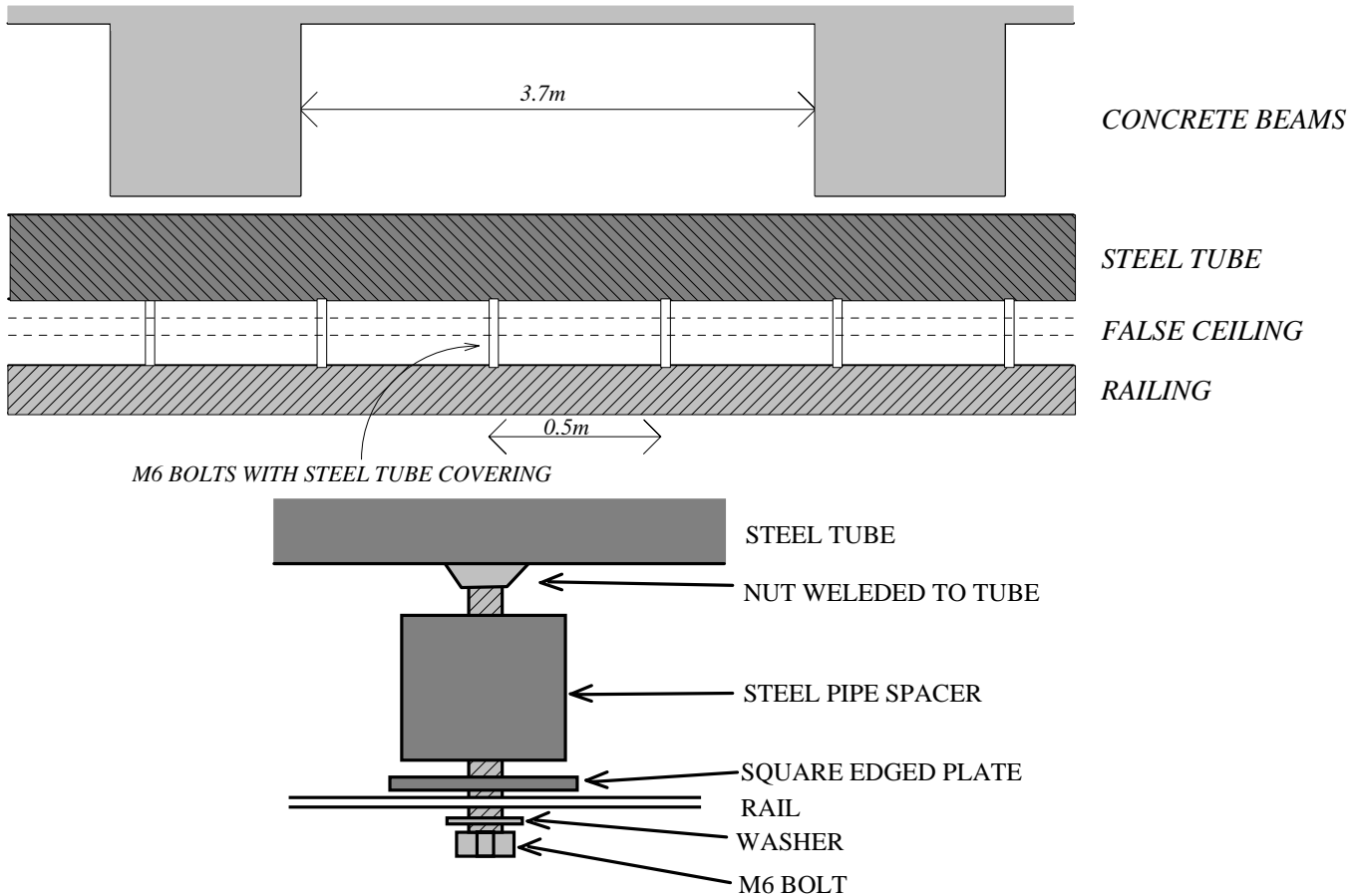
Hollow Profiles - These type of rails are widely used in overhead conveyors, light cranes and sliding doors. Available from many distributors and many types were surveyed. The final choice was made by Eltrak, which can take a load rating of 650kg (the highest of any of the options). The drawbacks are that the structure will not be easy to clean once in place, and attachment to the concrete beams in the ceiling will not be straightforward. The carriages, however, are of good quality without being heavy and smaller, lighter carriage models are available (if needed to carry cables)



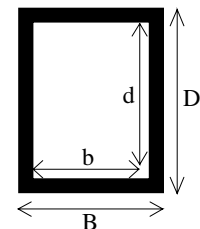
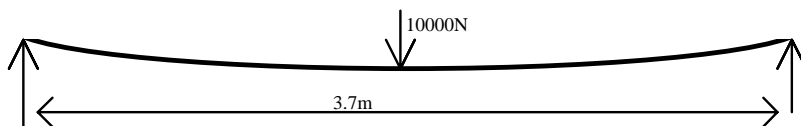
Suppliers: B&D Slide-a-Track, GIS cranes, Unistrut, Eltrak.

Constructional Details:

The manufacturer of the railings chosen recommends (for loads over 650kg) that the rails should be fixed from above every 50-60cm. This poses a problem since the concrete beams in the roof occur only every 3.7m. To overcome this a strengthening structure will have to be placed between the concrete beams and the rail. A simple steel tube would be suitable but it is important to work out what dimensions are required for the loads that will be placed upon it. The basic configuration will be this:



If we assume (in the extreme case) that the beam is simply supported at both ends with 1000kg load at the midpoint.

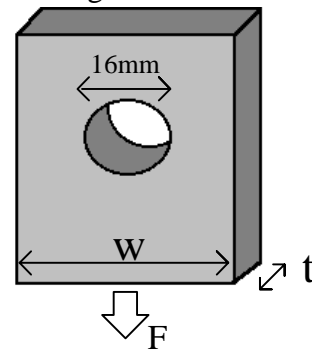


For this cross sectional shape and loading condition we know that

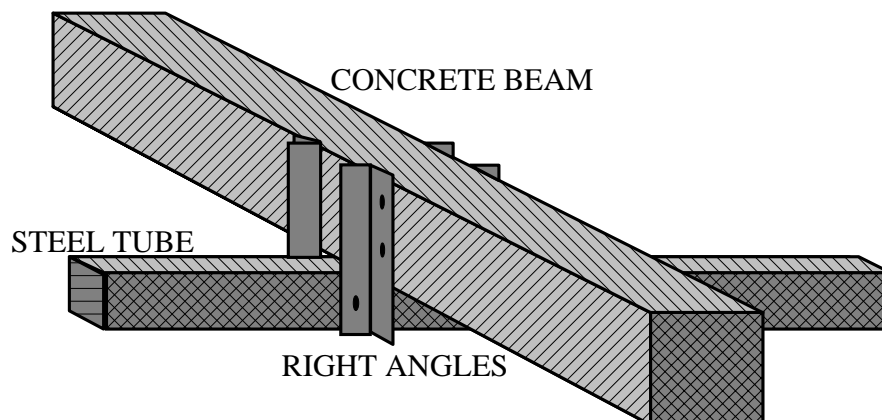
$$I = \frac{BD^3}{12} - \frac{bd^3}{12} \text{ and } \sigma = \frac{My}{I}$$

and that the minimum yield stress on the beam (for this type of steel) is 350MPa. We let $M = \frac{3.7}{2} \times 10kN = 18.5 \times 10^3$ and using a spreadsheet and exploring many possible dimensional combinations it was found that the best size for the tubing would be 100x100mm, 5mm thick. (keeping in mind a restriction that the tube could no be more than 120mm tall so as to fit between the concrete beams and the false ceiling.

Also required is a way to fix the tube to the beams. The solution was to use right angled steel bolted to the tube and into the concrete. Once again it is important to use the right size and thickness for the expected loads. The right angled bracket it is simplified to a simple plate with a hole (for a 16mm diameter bolt) in the middle. Note that the height of the plate is not important in this circumstance. The maximum stress that exists in the plate will theoretically be



$\sigma = \frac{3F}{wt}$, where F=10000N and w and t are the width and thickness of the steel plate respectively. For the right angle steel available the minimum yield stress is 250Kpa, and using preferred values bracket dimensions of 50x50x3mm were chosen to satisfy the criteria.



The steel tube covering the M6 bolts is used purely to keep a constant spacing between the tube and railing, and not in any supportive manner. The tube has an outside nominal bore of 32mm (42.4mm outside diameter, 4mm wall).

The installation of the steel structure (above) was done by a contractor. Three quotes were obtained from different buliders and engineering firms as outlined below.

NAME	COMPLETION TIME	COST
SKILLED ENGINEERING	2-3 DAYS	\$3730
HINDOFF ENGINEERING	2-7 DAYS	\$422.83 PER DAY
RAY GATT	2 DAYS	\$1150

Ray Gatt was chosen for the contract on the grounds of cheapest price, short completion time and ability to start the job quickly.

MOTORISATION:

The propulsion of the carriage needs to be of an almost ideal quality. That is, fast acceleration and braking, a wide range of speeds (from crawling to fast walk) and very quick response so as to follow erratic movement that humans can make. The motor system should be as lightweight as possible while still powerful enough to satisfy these criteria. An important aspect of the motorisation system is the driving method, ie how is the motor to actually push the carriage along the track.

An electric motor was settled on as a basic instrument for transport. Although AC motors are lighter and cheaper, a DC type would be advantageous in the fact that they are a lot easier to reverse and vary the speed. There a number of speed controllers available to suit any DC motor that is used; this is also true for AC motors but the controllers are much more expensive and generally not as flexible in their applications. The most suitable DC model would be a Shunt or Permanent Magnet motor, rather than a Series type. This is because a Series motor will maintain a constant torque at a given input voltage; thus the more load that is put on the motor, the slower it goes. This is not satisfactory for the application at hand, where we need constant given speed. This is what the Shunt and PM motors provide; a constant speed at a given voltage. If the load increases, the motor will draw more current to cope with this (up to a point, of course).

Before a thorough investigation of the alternatives was undertaken it was important to know some detail of the parameters that the motor should match, ie power, torque and RPM. (Only two actually need be known due to interrelation, as will be shown)

To discover the torque required the required acceleration needs to be found and since there was no firm data on normal accelerations experienced during walking an approximation was taken. The maximum accel/deceleration will be experienced when the subject starts and stops walking. Thus if we assume that the person is walking at $2.3ms^{-1}$ (actually nearly jogging pace) and comes to a stop over 0.5 metre then the deceleration (using $v^2 = u^2 + 2as$) works out to be $5.4ms^{-2}$. If we further assume that the harness is carrying half of a large persons body weight ($\cong 77kg$) then the maximum force that the motor will have to provide (by $F=ma$) is 416N. (This obviously does not take into consideration the weight of the motor, friction or cable drag) Initially a driving wheel diameter of 40mm was intended, and this gives a required torque of $8.32Nm$.

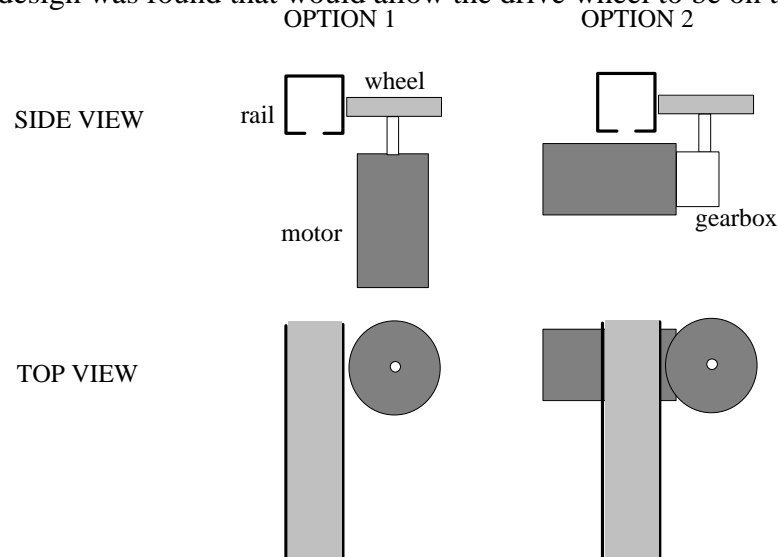
The RPM required from the motor will depend on the size of driving wheel used and gearbox reduction (if used). With the 40mm diameter driving wheel, and for a velocity of $2.3ms^{-1}$ this requires 1100RPM ($115rad s^{-1}$) at the output shaft.

If the formulae for torque, revolutions and gear reductions are examined, and using the parameters discussed above, we come up with the relation $T_m \omega_m = 970$, where T_m is the torque required at the motor (in Nm) and ω_m is the shaft speed at the motor (in radians per sec). For RPM use $T_m \omega_m = 9256$. Note that this is independent of the gearbox ratio (if one is used) and the driving wheel radius (which is really just a simple gearbox anyway). This is not strange because as it happens this is also the formula for rotational power. Therefore we will require a 970 Watt motor. (Assume 1.1KW as this is the nearest preferred value that motors are manufactured in).

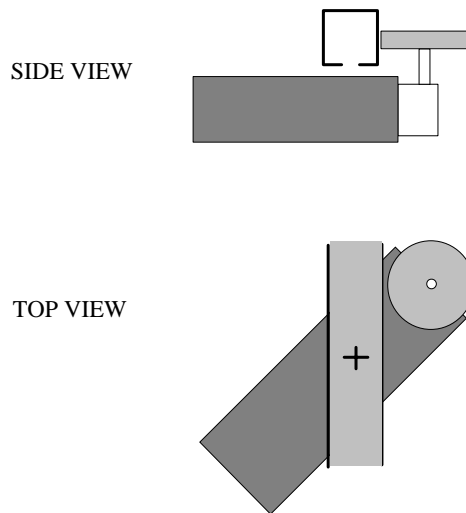
A large number of local dealers were contacted in order to obtain advice and prices for such a motor. One suggestion that arose in a conversation with a supplier was that a driving wheel of 40mm diameter will be too small, and will probably slip at the high revolution rate that shall be needed. Thus a larger wheel should be used that

can provide the same transverse velocity but at a lower RPM. Note that the size of the wheel is also restricted by practical and space limitations. A larger diameter of 100mm was chosen. Now for the same transverse speed a shaft speed of 440 RPM would be needed. This would require gear reduction, and by examining the available gear ratios and motor speeds the best combination will be a 1800 RPM motor with a 5:1 reduction. (This gives a maximum output of 360 RPM at the shaft and thus a velocity of 1.8ms^{-1} , still a very brisk walk or 6.5 km/h) With the larger driving wheel the risk of slipping is reduced and a fast velocity is still obtainable.

The configuration of the motor/driving wheel with respect to the track was not given a lot of consideration at the beginning of the project, as it was assumed that it would be a straightforward mechanical activity. This may have been an error of judgement as the size and weight of the motor and gear box were seriously underestimated. Initially there were two options considered for the connection of the drive wheel to the rail. As shown below, the motor could be mounted vertically on the side and the drive wheel would act axially, or the motor could lie horizontally and the drive wheel would contact via a worm gearbox. The weight and length of the motor and motor-gearbox combinations deemed these configurations to be unacceptable. A hybrid design was found that would allow the drive wheel to be on the side of the



rail, yet the centre of gravity of the motor/gearbox would be directly under the rail, thus not overbalancing in either direction.



Another wheel may be added on the left side (on the above diagram) of the rail to add stability and give better grip to the driving wheel.

The motor setup finally chosen was supplied by Reynolds Dynamics.

MOTOR

BALDOR 0.75Kw Permanent Magnet, Flange mounted Motor.

Base Speed = 1750 RPM, Armature voltage = 180V

\$611.00

GEARBOX

PENFOLD MSP Worm Gearmotor. Model MSP55.

Ratio 5:1

\$423.00

CONTROLLER

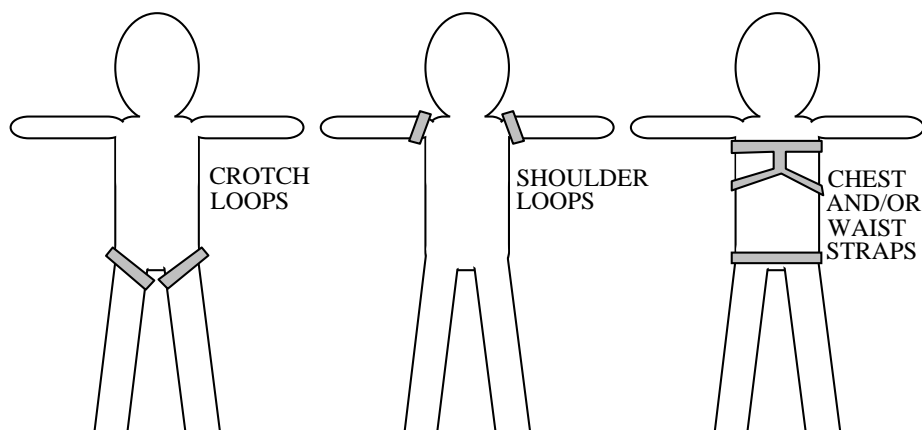
PENTA-POWER KBRG 255 Regenerative Drive.

Full wave, 4 Quadrant Speed and Torque control.

\$530.00

WEIGHT RELIEF

The bearing of the patients weight is a critical factor in the design of the system. The most obvious component is the harness itself; it must be comfortable and minimise obstruction to gait while still being functional. The main elements being considered to construct the harness are shown below; crotch loops (similar to a climbing harness), shoulder loops (connected to each shoulder or from a midpoint between the shoulders) and chest/waist straps.



Naturally no one harness will be suitable for all people using the device, but a basic model that is adjustable to suit a wide range of users would be a good basic building block. The harness should be easy to get into, and detachable from the rest of the overhead rail system so that the patient may put on the harness while in a wheel chair or just standing, and then be 'clipped' into the carriage above. Foam or material padding may be added if and where necessary; commonly straps can be painful under the armpits and on the chest. One design that may cover many of the above points satisfactorily would be the use of a waistcoat arrangement and crotch loops. This would bear a large proportion of the weight around the chest area and less under the arms and inner thigh. A waistcoat would be beneficial also since it would be simple to put on and the appearance would be less 'threatening' to a patient than a mass of straps, clips and buckles. All of these ideas and requirements were put to a designer at PARADYNAMICS, a company which produces many custom made harnesses for all sorts of applications. As of 23.2.95 the design is still being worked on by Jo Chitty at Paradynamics.

Mechanically the load bearing requirements of the system could be achieved in a number of ways:

- **STATIC BEARING**

The harness is connected directly to the carriage above with no other fittings.

- **SPRING SUSPENSION**

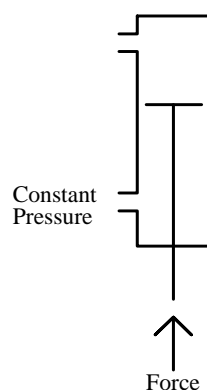
A spring (perhaps dampened) is placed between the carriage and the harness. This will allow for the vertical movement of the persons body as they walk but unfortunately will not present a constant upwards force during this movement. (Less force will be acting on the body when the person is at the higher stage of their gait) Depending on the amount of weight taken by the spring, the user may also experience 'bouncing' as they walk (due the uneven forces acting at stages of their gait)

- **MOTORISED COMPENSATION**

The harness could be connect to a motor above which would be able to adjust the amount to upward force instantaneously according to the vertical position of the person walking. This is certainly achievable but the complexity of the design is a large negative factor when a simpler solution may be available.

- **PNEUMATIC ACTUATION**

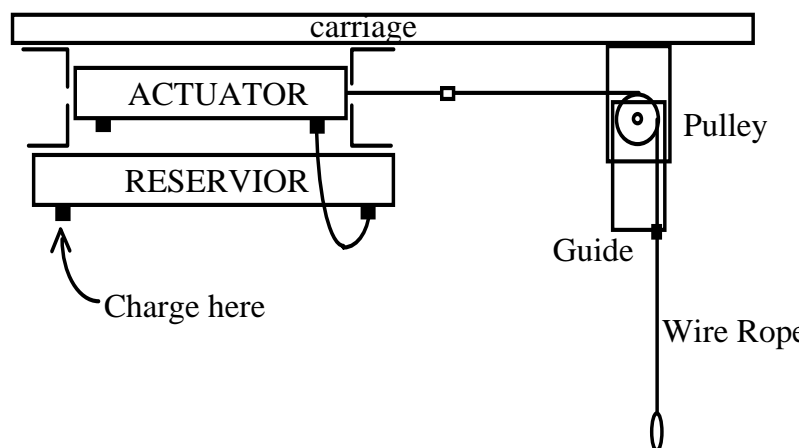
A pneumatic system mounted on the carriage would be able to (with a relatively simple configuration) provide a constant upward force on the harness regardless of the user's vertical position. Note that hydraulics were dismissed because pneumatics generally provide a quicker response, less maintenance, clean running and compressed air is readily available at most clinical settings. After investigation and consultations with pneumatic suppliers, this method proved as the most promising because of its cost effectiveness and relative mechanical simplicity.



If a constant pressure is applied in the lower chamber of a pneumatic actuator, while the upper is left open, the upward force will always be the same regardless of the piston position (the characteristics required). The upper exhaust point may also have a valve placed on it so that the velocity of the upward movement of the piston (which, unloaded, could be very high) can be controlled.

Initially it was assumed that the pneumatic system would be fed by a compressor via air hoses trailing the carriage, and that there was no other option. Fortunately a suggestion was made by a pneumatics consultant that this was not necessary and that a charged reservoir (ie, a small compressed air cylinder) could be used and would be small enough to be mounted on the carriage. Thus the reservoir would be 'charged' before use and then operate independently of the compressor, eliminating the trailing hoses (which would add significant drag and weight). Another early intention was to provide a new compressed air connection to the biomechanics lab running through the ceiling from the compressor in the workshop. This will no longer be necessary as Rehab tech has acquired a new compressor for the workshop and thus the old compressor can be wheeled into the biomechanics lab whenever needed.

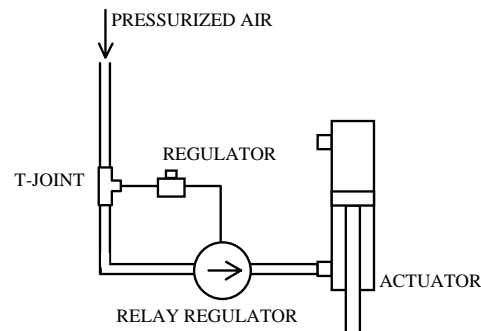
The configuration of a possible pneumatic system is shown below. The charged reservoir is of appropriate size and weight to be fitted below the actuator.



A rope is connected to the end of the piston, which travels over a pulley and through a guide. The stroke length of the piston will be 25cm. This is more than is necessary (since the vertical displacement of a persons body when walking is around 5cm) but the extra length will be useful for patients with unusual gaits and when taking up slack rope.

Initially designs and prices were discussed with a representative of FESTO pneumatics. After some ground was covered it became difficult to contact the consultant and so REXROTH pneumatics were contacted for further action. In addition to previous ideas (presented above) the representative suggested the use of a 'zero gravity' system often used in industrial lifting situations. The device will attach to a load and when activated a person may manipulate the object as though it is weightless, even though it may weight hundreds of kilos. This would also be suitable for our requirements, but a limiting factor is the cost, since many precision valves and regulators are incorporated into the control system.

One problem with the system pictured above is that the downward movement of the piston is hampered by the regulator and exhaust hole size. To combat this a relay regulator is used in the system in the following manner.

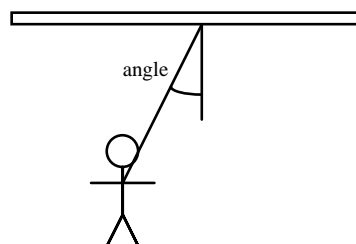


The relay regulator is able to act more sensitively than a normal regulator. The manual regulator is instead used to 'set' the pressure at which the relay regulator should operate at. This proved in practice to give better response but with larger cylinders exhasausting air was still a problem. Blain Barber from Rexroth offered the temporary use of a more expensive relay regulator which is over 100 times more sensitive than the one previously tested. The relay should be available in the week before 1.3.95 for a few days, after which it must be passed on to another customer by Rexroth.

CONTROL

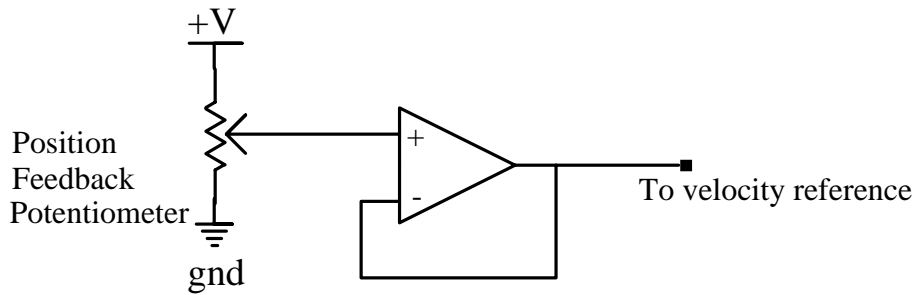
The type of control mechanism needed for the carriage to follow a person walking is best determined after the motorisation stage has been completed. It may not be necessary to implement any further control mechanisms at all due to the flexibility of the DC motor controller.

The feedback from the carriage will be through a potentiometer mounted at the axis of the wire rope guide. This will then return a signal proportional to the angle between vertical, and the position of the person walking.



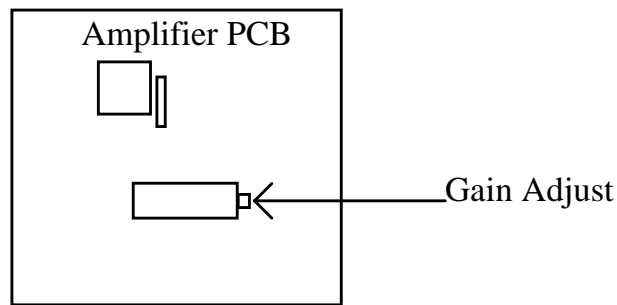
Thus a velocity request signal can be sent to the motor controller directly from the potentiometer. Acceleration, deceleration, offset and gain are adjustable on the controller and this will probably prove to be sufficient to give good performance for the system. If, however, this proves to be unacceptable an intermediate control system may be implemented to improve the movement following characteristics. The only foreseeable problem with this control system is that the carriage will always have to be a finite distance (which will be proportional to the walking velocity) behind the person.

One possible simple control system would be an integrator.



Using this simple circuit the carriage would no longer lag behind to walker. Instead the control system would accelerate the carriage until it was directly above the person and then slow to the persons walking speed. There will still be overshoot problems and possible uncontrolled oscillation involved with this design, but if this was to be implemented these obstacles could be overcome.

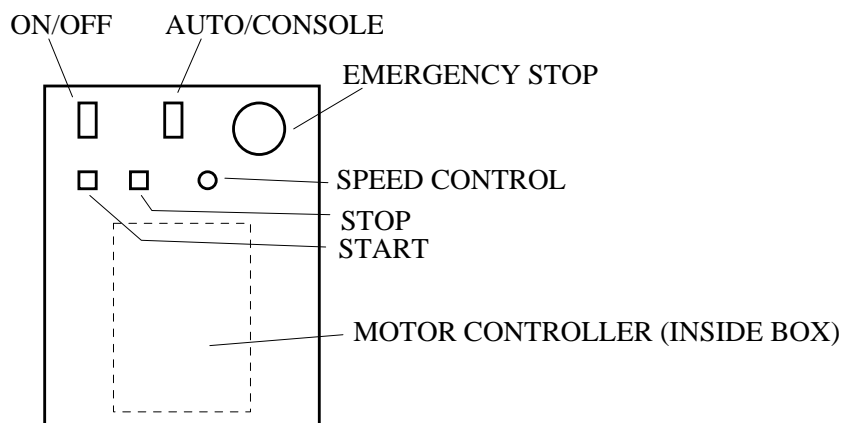
Since the motion of the potentiometer installed on the carriage will not be accurate enough, a small amplifier will be mounted inside the control box with the purpose of increasing signals from the pot. Thus a small movement will correspond to a larger increase in motor speed. (The gain of this small amplifier will be adjustable as shown below)



To change the gain adjust the multi turn trimpot. (Clockwise to increase gain, anti-clockwise to decrease gain). The gain is adjustable from 1 to 21. Note that if the gain is set too large the movement of the carriage system may become unpredictable and too sensitive.

CONTROL BOX

At one end of the biomechanics lab there will be a control box to supply power and control to the motor system on the carriage. The box will need to be large enough such that the motor controller does not overheat.



The functions of the controls are:

- ON/OFF Supply power to the control unit.
- EMERGENCY STOP Cut all power to the control unit. To activate the emergency stop simply press the large button. To resupply power pull the button out. Be sure (for safety) that the ON/OFF switch is OFF before resetting the emergency stop button.
- START Start the motor controller.
- STOP Stop the motor controller.
- AUTO/CONSOLE This switch determines whether the speed of the motor is controlled by the potentiometer on the carriage or by the speed control on the console. Before this option is change be sure that the speed control on the console is set to ZERO. (If not the motor may accelerate unexpectedly)
- SPEED CONTROL If the AUTO/CONSOLE switch is set to CONSOLE then the speed of the motor is set by this dial.

OPERATION:

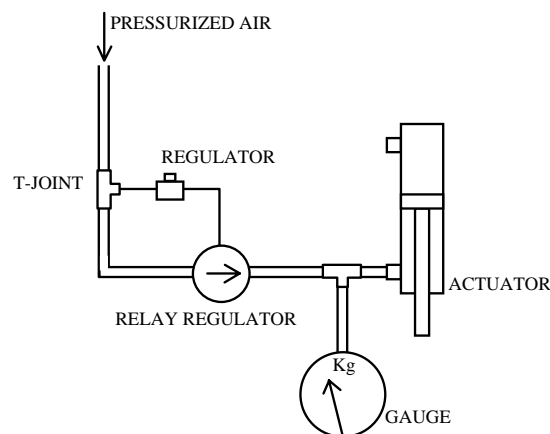
- Turn power on at switch. Button should illuminate when power is on. If button does not illuminate
 1. Emergency Stop switch may be pushed in: pull out to restore power
 2. Cord may not be connected and/or turned on at wall socket (near west windows)
- Choose AUTOMATIC control or CONSOLE control.
 1. AUTO control means that the trolley will follow the subject at walking speed
 2. CONSOLE mean trolley speed is controlled by knob on control panel.
- Press START button to start motor.
- Press STOP when the motor is required to be off.
- If a micro switch is triggered at the extremities of the walkway, the trolley will automatically stop moving as a safety precaution. To restart the trolley again simply press START. Note that if the microswitch is resting against the metal strip on the roof, the trolley will have to be manually moved a little distance to release the switch, and allow the motor to be operated using START.
- In an emergency the large red emergency switch can be hit which will cut all power to the system. (Pneumatic connections will still operate however)

APPENDUM: 18.12.1995

After unsuccessfully attempting to get a harness constructed by Paradyamics and Betty Wishart Surgical, the job was given to Dave Marsh of Tech Assist Products. The design was discussed and a completion date of early January 1996 was given, for a cost of approximately \$200.

An option was given that the harness could be tested at Tech Assist to Australian standards for \$100 + price of one garment (~\$200), but this opportunity was not taken at the time. If the prototype garment is suitable this testing may be requested at a later date.

Additions were also made to the pneumatic system on the overhead harness. A pressure gauge with enlarged face and a kilogram scale was added, so that the amount of lift in kilograms can be dialled up using the regulator. A new regulator with condensing chamber was purchased so that connection to the compressor is simplified, and so ensure that the maximum working pressure of the hose (10 Bar) is not exceeded, since the available pressure from the regulator can be up to 12 Bar.



APPENDUM: 17.1.1995

Walking harness received from Tech-Assist for a cost of \$180. New harness uses pressure around pelvic hoop and chest, as well as support in the armpits to provide lift, avoiding crotch loops.