# Designing and Implementation of a Blackboard Cleaning Manipulator

Lab Based Project Report

MIED, IIT ROORKEE

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# Problem Formulation

## 1 Abstract

The objective of the project is to explore various manipulators that allow movement in Cartesian coordinates. The concept is in context to the blackboard cleaning activity after each class session. The project is composed of various concepts that cover the domain of mechatronics. Manipulators will be tested for various drivetrains, such as motors and transmission mechanisms. 3-D printers are a good example that will be used in this project. The guided movement in x-y direction with the help of a timing belt provides the best possible movement in the Cartesian plane. After the design phase, controllers that will efficiently control the system to provide the most energy-efficient manipulation will be developed. Motor controllers and related circuits will be added to complete the control objectives. Finally, a design and cost report will be prepared and the required materials will be procured through the funding promised by our supervisor. Cost optimization and effective design play a very vital role in the success of the project and the goal is to perfectly maintain a balance between the two. The finalized design will be fabricated and implemented in one of the lecture rooms of the department. This will be the conclusion of the project which will serve effective user-controlled blackboard cleaning with easy serviceability, replace ability, and maintenance.

The proposed timeline is given below in Figure 1. All the objectives are not completed due to COVID-19.

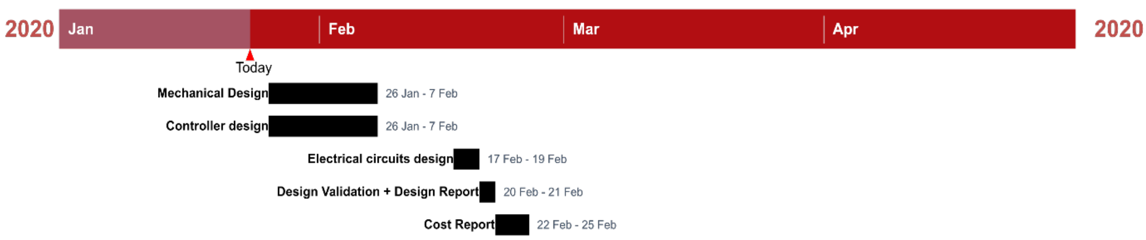



Figure 1: Updated Timeline as per COVID19 Situations

# 2 Motivation

- Cleaning blackboard each time it gets filled is a tedious task.
- Often professors don't clean the blackboard and the next professor in the class faces a problematic situation.
- Until now the manipulations used to clean boards are based on unidirectional motion.
- Those manipulators are based on complete cleaning each time they are activated.
- Complete cleaning might not be required every time and hence cleaning a partial area is the need.
- The problem can be easily addressed by a bi-directional Cartesian manipulation.
- Manipulation is highly inspired by 3D printing technology.

# 3 Problem Definition

To design and implement a classroom Board Cleaning Manipulator (BCM) based on movement along Cartesian directions, which will help cleaning the board automatically after the action is triggered by the user.

# 4 Methodology

- With a proper force calculations, weight estimation of the system, the drivetrain will be modelled. Appropriate motors and transmission system is chosen considering the feasibility, cost and manufacturing into consideration.
- The drivetrain will facilitate the Mechanical design of the overall assembly of the system with appropriate component positioning in the available space.
- The electrical power system will be installed based on chosen motors and micro-controllers and a closed loop feedback system will be developed.
- Proper motion planning strategies will be developed and executed to increase the versatility of the system.

# Mechanical Design

## 1 Modeling

For effective designing of the Board Cleaning Manipulator, a list of expectations for the final design were produced, and based on that, several design considerations were decided.
Design Considerations:

- Cost
- Manufacturing
- Robust
- Safe
- Easy Handling
- Classroom Friendly
- Fast Response
- Easy to Fabricate

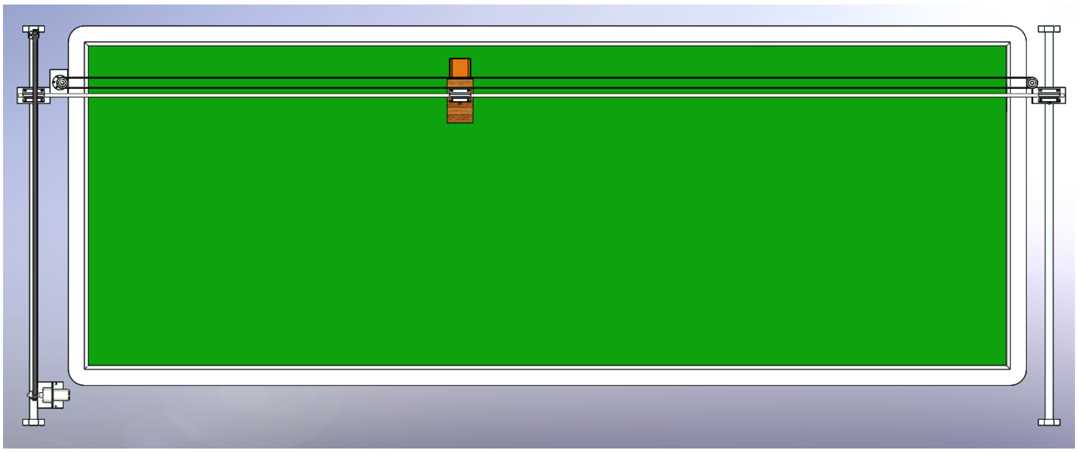


Figure 1: Front View (The CAD Model was developed using SOLIDWORKS 2019)

Further, the design was optimised to maximize use of OEMs to make the parts/assemblies replaceable in case of any damage.

# 2 Design Evolution

There were various steps and iterations for our design evolution. Design generation began with a design breakdown to the number of functional components, namely, the Frame, Path Mechanism, Mountings and Supports. Further iterations based on several advantages and different classroom scenarios were done. Space allowance for a projector screen and minimum use of space were some essential factors for the design changes. Finally, we came up with this design. The list of Components:

| Part No. | Part Name | Material | Quantity | Comments |
|---|---|---|---|---|
| 1. | Board | OEM | 1 pc | Green Board |
| 2. | Duster | OEM | 1 pc | Board Cleaning Duster |
| 3. | Duster Mounting Bracket | Wood | 1 pc | To mount Duster on Board |
| 4. | Square Channel (20x20x2 $mm^3$) | Aluminium | 2 m | Vertical Supports |
| 5. | Wall Mounting Bracket | Aluminium | 4 pcs | Brackets for Mounting Sq. Channels |
| 6. | Sq. Channel Roller (20x20) | OEM | 2 pcs | Roller on Sq. Channel |
| 7. | Motor 1 (100 RPM) | OEM | 1 pc | Motor for Vertical Motion |
| 8. | Motor 2 (300 RPM) | OEM | 1 pc | Motor for Horizontal Motion |
| 9. | Motor Mounting 1 | OEM | 2 pcs | Johnson Motor Mounting Bracket |
| 10. | Motor Mounting 2 | Aluminium | 1 pc | Motor1 Mounting Bracket |
| 11. | Timing Pulley 1 | OEM | 2 pcs | Pulley for Vertical Motion |
| 12. | Timing Pulley 2 | OEM | 2 pcs | Pulley for Horizontal Motion |
| 13. | Pulley Mounting 1 | Aluminium | 1 pc | For Pulley of Vertical Motion |
| 14. | Pulley Mounting 2 | Aluminium | 1 pc | For Pulley of Horizontal Mounting |
| 15. | Linear Ball Bearing Slide | OEM | 3 pcs | For Circular Tube Support |
| 16. | Circular Tube (8mm x 2mm) | Aluminium | 1.8 m | For Horizontal Path of Duster |
| 17. | Timing Belt | OEM | 10 m | For Movement |

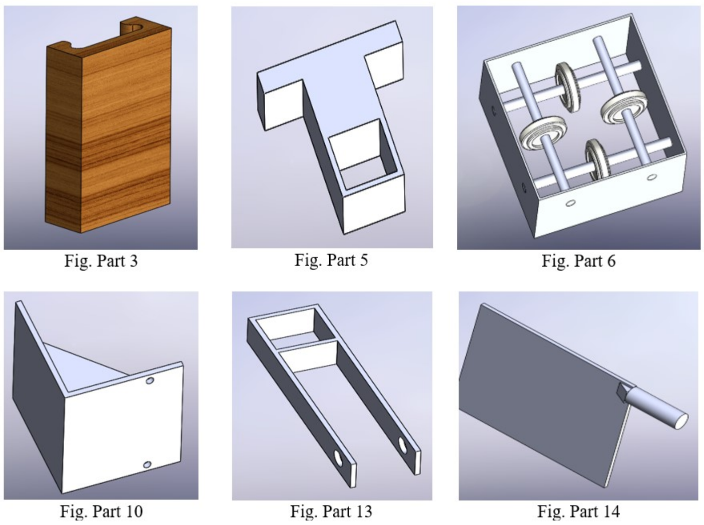
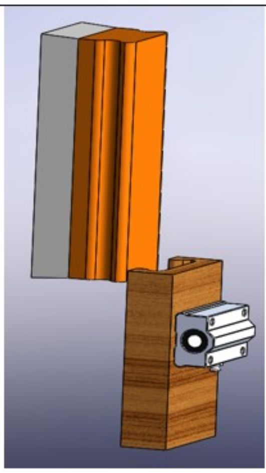
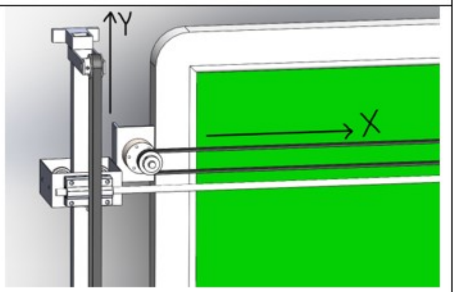



Figure 2: Some Components

# 3 Advantages

| | | |
|---|---|---|
| **1. Removable Duster** | The duster can be easily unmounted to remove dust particles or even change to a new one. Also, it will provide liberty to the user to use the duster manually. |  |
| **2. Cartesian System** | The movement of the duster is along the Cartesian Coordinate Axis System. Further Motion Planning implemented to find the appropriate path. |  |
| **3. Easy Mounting** | All the components can be easily mounted and unmounted for any kind of replacements. |  |

# Gear Train Design

## 1 Powertrain Selection

The powertrain selection was done keeping into consideration the cost and reliability of mechanism .The aim was to keep the system lightweight and easy to operate. The Leadscrew mechanism was bulky and costly too. Next best alternative was to use a pulley and belt ,but a pulley might slip considering the load and tension in the belt. Timing belt and pulley system do not slip and are also lightweight with greater reliability. SO timing belt was selected for the purpose of this project.

## 2 Calculaltions

All the calculations were performed considering:

- Board length – 1.5 m (approx)
- Breadth -1 m (approx.)
- Time taken to clean the complete board - 2 min (max)

The overall methodology is as follows:

1. Calculating the force required on duster to properly clean the board.
2. Finding the motor power and pulley dimensions according to board dimensions and time limit.
3. Calculating the width and type of timing belt from the above force for the purpose of horizontal motion.
4. Similar procedure for the vertical motion.

### 2.1 Calculating Required Force on Duster

- The above calculation was done by applying two different known loads the holding load which pushes the duster in direction of board and the displacing load with which the duster could be moved around the board.
- The displacing load was checked if the board was being roughed properly for corresponding holding load.

- The above procedure was done until we found the correct displacing load which was about 10N.
- We took a factor of safety of 2 and considered the load to be 20 N for uncertainties in our experiment .

## 2.2 Calculating Motor Power and Pulley Dimensions

- Considering the time limit the motor should be able to cover the length of board in around 12 seconds. i.e the speed of belt was about 0.125 m/sec.
- The pulley and motor needed to be selected considering two things:
  - The motor power rating should be as low as possible to keep low costs.
  - The motor and pulley assembly should provide sufficient torque and speed to clean the board in time.
- Various iterations were made considering the two conditions . The best was to use a 300 rpm motor with 34 kg cm of rated torque along with a pulley of 36 teeth 2 mm pitch and 25 mm diameter. Gear ratio is kept as 1 for simplicity.
- The motor was selected iterating to the load rating of timing belt calculated in next step and also considering rated load given for timing pulley to work properly.

## 2.3 Calculating Dimensions of Timing Belt

- The timing belt was selected according to the handbook of timing belts and pulleys by SDP/SI.(See Appendix Figure 1)
- GT3 belt was chosen being superior in performance than other belt types. Service factor is taken as 1.5 and the design load (considering rated torque 0.35 Nm) is 0.52 Nm.
- As seen from figure below at 300 rpm and 0.52 Nm of torque the timing belt of 2mm pitch is sufficient.
- The belt length is approximately 3m and belt length correction factor is 1.5 for this length.
- The belt width can be selected from chart (Appendix figure 2) and it comes to be 6 mm.
- Now the belt length width pitch and type is known . The pulley width is same as belt width.

- The initial tension in belt is given by following formula and it comes to be 23.84 N.

$$T_{st} = \frac{0.812DQ}{d} + mS^2 \tag{0.1}$$

  where,

  - $T_{st}$ = Static Tension per Span (lbf.)
  - $DQ$ = Driver Design Torque (lbf. in.)
  - $d$ = Driver Pitch Diameter (in.)
  - $S = V/1000$ (ft./min)
  - $V$ = Belt Speed = (Driver Pitch Dia. × Driver RPM)/3.82 (ft./min)
  - $m$ = Mass factor

# Motion Planning, Control System and Power System Design

## 1 Motion Planning

### 1.1 Concept

Motion planning, a combination of path planning as well as temporal decision making of state paremeters is a computational problem to find a sequence of valid configurations that moves the object from the source to destination. In our project, we assume constant velocity and hence the absence of temporal characteristic makes the problem a simple path planning problem. Thus, we aim to find the series of valid configurations of duster to erase all the blackboard.

A basic motion planning problem is to compute a continuous path that connects a start configuration(S) and a goal configuration(G). If the robot is a single point (zero-sized) translating in a 2-dimensional plane (the workspace), C is a plane, and a configuration can be represented using two parameters (x, y).The blackboard in our project is the configuration space. Furthermore, we have assumed that there is no obstacle in the configuration space and thus, the whole blackboard is a free space.

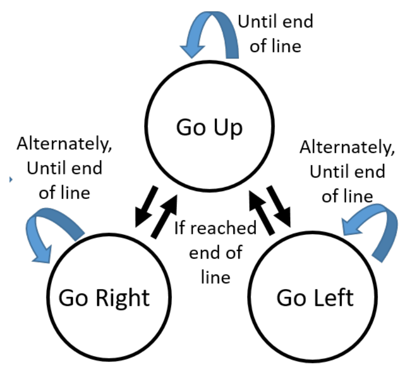



Figure 1: Behavioral Planner Schematic

## 1.2 Behavioral Planner

The governing planner serves to be a finite state machine based decision making body. This segment is responsible for deciding the parent policy of either moving vertically up/down or horizontally left/right. We follow a simple algorithm of deciding which policy the end-effector i.e. Duster holder takes such that it follows the desired path. Our aim is to cover the whole blackboard and for that the blackboard was divided into many horizontal section so that the duster don't have to cover the same area twice. The simple implementation of this planner is given in Figure 1.

## 1.3 Simulation

In our motion planning algorithm, for a particular blackboard, the input is the height and length of the board. The length and width of the duster is taken constant. A proper implementation of the simple path planner and behavioral planner can be visualized from the figure 2 below.

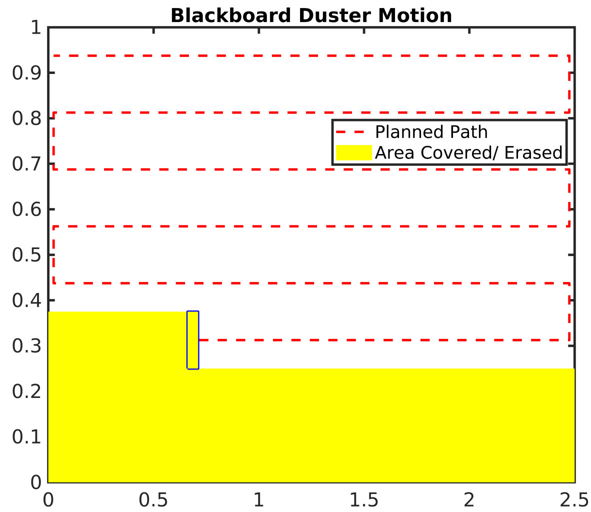



Figure 2: BCM in action: Planned path and Erased Area by the Duster

# 2 Control System

A simple PID based control is formulated with both the feedforward and feedback segment which are implemented in accordance with the effective design of the BCM assembly. The control is applied on the voltage applied to the actuators which are controlling the x and y coordinate motion of the duster holder. The disturbances will be taken into account under the feedforward segment based on the error in the approximation of board friction as well as the trajectory tracking errors.

The feedback system is constructed with the help of linear potentiometers which are used either along the x-y coordinates of the board to be eraased or rotational potentiometers attached to the actuator itself and converts between the rotation of the actuators and the the position of the end-effector. Thus the complete planning and PID based control pipeline can be visualized as in figure 3 below.

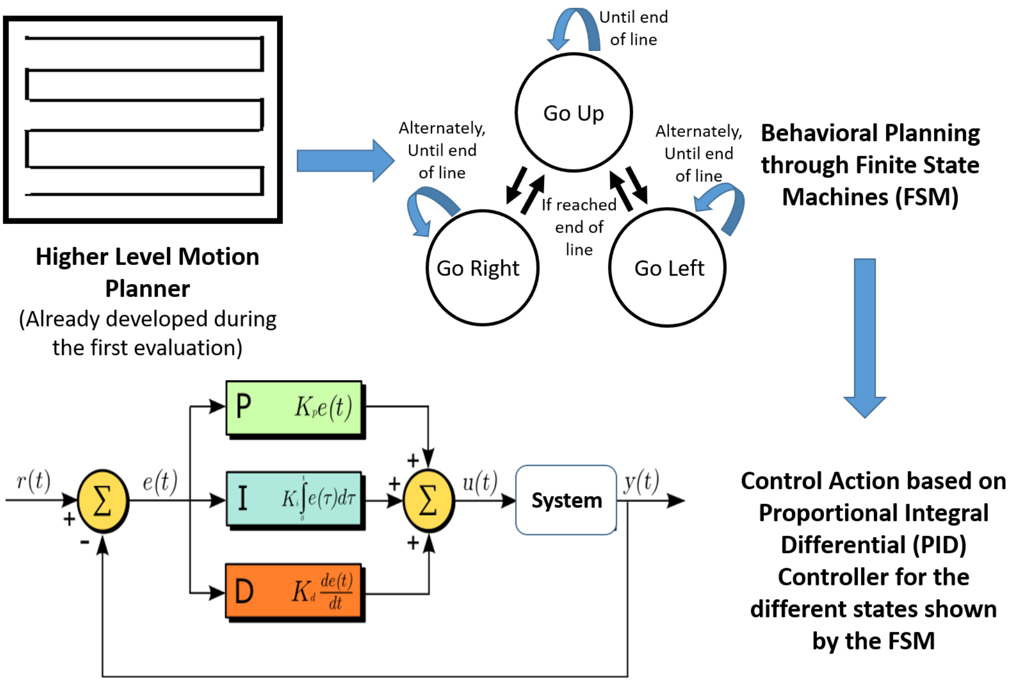



Figure 3: Complete Planning and Execution

## 3 Power System

Power system is basically defined as the flow of power from the source to the BCM apparatus. The significance of such a system is self explanatory and drive the complete functioning. The key segments of the power system designed for the BCM appratus presented in this work are as follows:

- An adapter will be used to connect the BCM power node with the 220 V Mains Supply. This supply will be used to power up the DC motors at 12 V each.
- A DC-DC converter will be used to drop the voltage from 12 V to 5 V in order to power up the potentiometers, moto-controllers as well as the micro-controllers.
- Appropriate switches will be insntalled such that there is an automatic enabling of all the circuits with a single button that can be used by the teachers.

- It was also taken into concern that the Mains supply should always be connected and any kind of hazardous circumstances dealing with such a supply is avoided.

The final power system coupled with the control system elements are shown below.

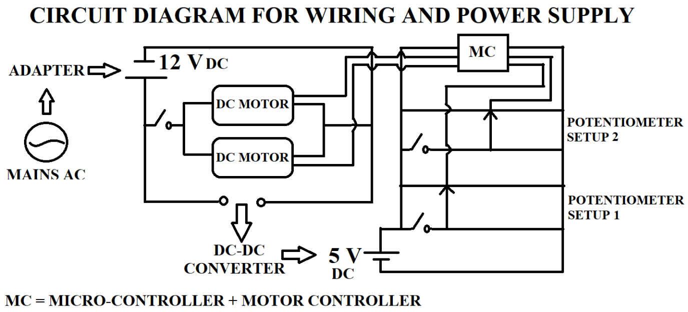



Figure 4: Combined Control System and Power System Schematic

# Manufacturing

## 1 Cost Report

| Part Name | Specification | Quantity | Total Price | Website |
|---|---|---|---|---|
| Duster Mounting Bracket | Wood Machining | 1 | - | No Link |
| Aluminium Tubes | Square Channel & Circular Tube | 1 Kg | Rs.220.00/- | Link |
| Mounting Brackets | Aluminium Machining | 0.6 Kg | Rs.450.00/- | No Link |
| Jonson Motor With Driver | 100 RPM | 1 | Rs.650.00/- | Link |
| Jonson Motor With Driver | 300 RPM | 1 | Rs.650.00/- | Link |
| Timing belt | Pitch: 2 mm; Width: 6mm; Length: 10 m | 1 | Rs.990.00/- | Link |
| Timing pulley | Pitch: 2 mm; 36 teeth | 2 | Rs.340.00/- | Link |
| Timing pulley | Pitch: 2 mm; 40 teeth | 2 | Rs.380.00/- | No Link |
| Jonson motor clamp | None | 2 | Rs.300.00/- | No Link |
| Arduino Uno R3 with Cable | None | 1 | Rs.425.00/- | Link |
| RM065 Potentiometer | 10k Ohm Trimpot Trimmer | 2 | Rs.118.00/- | Link |
| LM2596S DC-DC Buck Converter Power Supply | Input voltage: 3-40V; Output voltage: 1.5-35V(Adjustable) | 1 | Rs.140.00/- | Link |
| Power Adapter | AC 100-240V to DC 12V 5A 60W | 1 | Rs.650.00/- | Link |

So, the total approximate cost of a proper fabrication of the proposed BCM Assembly is calculated to be $Rs.5313 \times 1.5 = Rs.7969 \approx Rs.8000$.

# Appendix

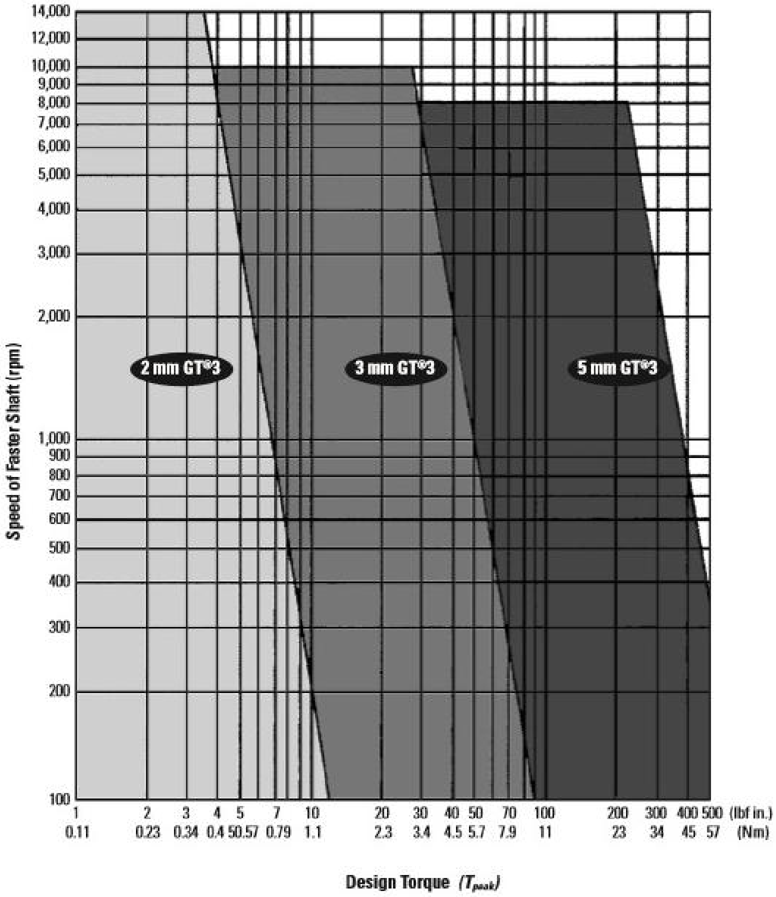



Figure 1: GT*3 Belt Selection Guide

**Table 33 (Cont.) Rated Torque (Nm) for Small Pulleys - 6 mm Belt Width**

*The following table represents the torque ratings for each belt, in its base width, at the predetermined number of grooves, pitch diameters and rpm's. These ratings must be multiplied by the appropriate width factor and applicable belt length factor to obtain the corrected torque rating (see **Step 7** of **SECTION 24**, on page **T-65**).*

**2 mm Pitch PowerGrip® GT®3 Belts**

| Belt Width (mm) | 4 | 6 | 9 | 12 |
|---|---|---|---|---|
| Width Multiplier | 0.67 | 1.00 | 1.50 | 2.00 |

| Number of Grooves | | 12 | 14 | 16 | 18 | 20 | 24 | 28 | 32 | 36 | 40 | 48 | 56 | 64 | 72 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pitch Diameter | mm | 7.64 | 8.91 | 10.19 | 11.46 | 12.73 | 15.28 | 17.83 | 20.37 | 22.92 | 25.46 | 30.56 | 35.65 | 40.74 | 45.84 | 50.93 |
| | inches | 0.301 | 0.351 | 0.401 | 0.451 | 0.501 | 0.602 | 0.702 | 0.802 | 0.902 | 1.003 | 1.203 | 1.404 | 1.604 | 1.805 | 2.005 |
| rpm of Fastest Shaft [Tabulated values are in Nm] | 10 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.23 | 0.27 | 0.31 | 0.35 | 0.39 | 0.47 | 0.55 | 0.63 | 0.71 | 0.79 |
| | 20 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.22 | 0.26 | 0.30 | 0.34 | 0.38 | 0.46 | 0.54 | 0.62 | 0.69 | 0.77 |
| | 40 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.22 | 0.26 | 0.30 | 0.33 | 0.37 | 0.45 | 0.53 | 0.61 | 0.68 | 0.76 |
| | 60 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.21 | 0.25 | 0.29 | 0.33 | 0.37 | 0.45 | 0.52 | 0.60 | 0.68 | 0.75 |
| | 100 | 0.10 | 0.12 | 0.13 | 0.15 | 0.17 | 0.21 | 0.25 | 0.29 | 0.33 | 0.36 | 0.44 | 0.52 | 0.59 | 0.67 | 0.74 |
| | 200 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.21 | 0.25 | 0.28 | 0.32 | 0.36 | 0.43 | 0.51 | 0.58 | 0.65 | 0.73 |
| | 300 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.21 | 0.24 | 0.28 | 0.32 | 0.35 | 0.43 | 0.50 | 0.57 | 0.65 | 0.72 |
| | 400 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.20 | 0.24 | 0.28 | 0.31 | 0.35 | 0.42 | 0.50 | 0.57 | 0.64 | 0.71 |
| | 500 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.20 | 0.24 | 0.28 | 0.31 | 0.35 | 0.42 | 0.49 | 0.57 | 0.64 | 0.71 |
| | 600 | 0.09 | 0.11 | 0.13 | 0.15 | 0.16 | 0.20 | 0.24 | 0.27 | 0.31 | 0.35 | 0.42 | 0.49 | 0.56 | 0.64 | 0.71 |
| | 800 | 0.09 | 0.11 | 0.13 | 0.14 | 0.16 | 0.20 | 0.24 | 0.27 | 0.31 | 0.34 | 0.42 | 0.49 | 0.56 | 0.63 | 0.70 |
| | 1000 | 0.09 | 0.11 | 0.13 | 0.14 | 0.16 | 0.20 | 0.23 | 0.27 | 0.31 | 0.34 | 0.41 | 0.49 | 0.56 | 0.63 | 0.70 |
| | 1200 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.20 | 0.23 | 0.27 | 0.31 | 0.34 | 0.41 | 0.48 | 0.55 | 0.62 | 0.69 |
| | 1400 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.20 | 0.23 | 0.27 | 0.30 | 0.34 | 0.41 | 0.48 | 0.55 | 0.62 | 0.69 |
| | 1600 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.20 | 0.23 | 0.27 | 0.30 | 0.34 | 0.41 | 0.48 | 0.55 | 0.62 | 0.69 |
| | 1800 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.20 | 0.23 | 0.27 | 0.30 | 0.34 | 0.41 | 0.48 | 0.55 | 0.62 | 0.69 |
| | 2000 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.27 | 0.30 | 0.34 | 0.41 | 0.48 | 0.54 | 0.61 | 0.68 |
| | 2400 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.26 | 0.30 | 0.33 | 0.40 | 0.47 | 0.54 | 0.61 | 0.68 |
| | 2800 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.26 | 0.30 | 0.33 | 0.40 | 0.47 | 0.54 | 0.61 | 0.68 |
| | 3200 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.26 | 0.30 | 0.33 | 0.40 | 0.47 | 0.54 | 0.61 | 0.67 |
| | 3600 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.26 | 0.30 | 0.33 | 0.40 | 0.47 | 0.54 | 0.60 | 0.67 |
| | 4000 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 | 0.19 | 0.23 | 0.26 | 0.29 | 0.33 | 0.40 | 0.47 | 0.53 | 0.60 | 0.67 |
| | 5000 | 0.08 | 0.10 | 0.12 | 0.14 | 0.15 | 0.19 | 0.22 | 0.26 | 0.29 | 0.33 | 0.40 | 0.46 | 0.53 | 0.60 | 0.66 |
| | 6000 | 0.08 | 0.10 | 0.12 | 0.14 | 0.15 | 0.19 | 0.22 | 0.26 | 0.29 | 0.33 | 0.39 | 0.46 | 0.53 | 0.59 | 0.66 |
| | 8000 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.19 | 0.22 | 0.25 | 0.29 | 0.32 | 0.39 | 0.46 | 0.52 | 0.59 | 0.66 |
| | 10000 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.19 | 0.22 | 0.25 | 0.29 | 0.32 | 0.39 | 0.45 | 0.52 | 0.58 | 0.65 |
| | 12000 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.18 | 0.22 | 0.25 | 0.28 | 0.32 | 0.38 | 0.45 | 0.52 | 0.58 | 0.64 |
| | 14000 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.18 | 0.22 | 0.25 | 0.28 | 0.32 | 0.38 | 0.45 | 0.51 | — | — |

| For Belt Length | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From | Length (mm) | 100 | 106 | 124 | 146 | 170 | 198 | 232 | 272 | 318 | 372 | 436 | 510 | 598 | 698 |
| | # of teeth | 50 | 53 | 62 | 73 | 85 | 99 | 116 | 136 | 159 | 186 | 218 | 255 | 299 | 349 |
| To | Length (mm) | 104 | 122 | 144 | 168 | 196 | 230 | 270 | 316 | 370 | 434 | 508 | 596 | 696 | 800 |
| | # of teeth | 52 | 61 | 72 | 84 | 98 | 115 | 135 | 158 | 185 | 217 | 254 | 298 | 348 | 400 |
| Length Correction Factor | | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 1.00 | 1.05 | 1.10 | 1.15 | 1.20 | 1.25 | 1.30 | 1.35 |

Figure 2: GT*3 Belt Width Selection Chart