



Ministry of Higher Education & Scientific Research

University of Kerbala

College of Engineering

Department of Mechanical Engineering

**Simulation and Multibody Dynamic Analysis of a Cam Based
Infinitely Variable Transmission**

A Thesis Submitted to the Council of the Faculty of the College of
Engineering/University of Kerbala in Partial Fulfillment of the Requirements for
the Master Degree in Mechanical Engineering /Applied Mechanics

By:

Minyar Al-Mullahassan

Supervisor:

Asst.prof Dr. Amjad Al-Hamood

March 2024

Sha'ban 1445

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ

دَرَجَاتٍ


صدق الله العلي العظيم

(المجادلة: من الآية 11)

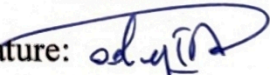
Examination committee certification

We certify that we have read the thesis entitled "Simulation and Multibody Dynamic Analysis of a Cam Based Infinitely Variable Transmission" and as an examining committee, we examined the student "Minyar Al-Mullahassan" in its content and in what is connected with it and that in our opinion it is adequate as a thesis for the degree of Master of Science in Mechanical Engineering.

Supervisor

Signature: 
Name: Dr Amjad Al-Hamood
Date: 5/5/2024

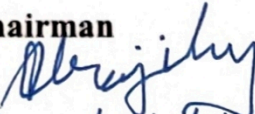
Member


Signature: 
Name: Odong I. Abdullah
Date: 5/5/2024


Member

Signature: 
Name: Muslim Muhsin Ali
Date: 5/5/2024

Chairman

Signature: 
Name: Ahmed Abdullah Al-Rajihy
Date: 6/5/2024

Signature: 
Name: Dr. Hayder Kusji
Head of the Department of Mechanical
Engineering
Date: 6/5/2024

Signature: 
Name: Dr. Haider Nadhom Azzib
Dean of the Engineering College
Date: 14/5/2024

Supervisor Certificate

I certify that the thesis entitled "**Simulation and Multibody Dynamic Analysis of a Cam Based Infinitely Variable Transmission**" was prepared by **Minyar Al-Mullahassan** under my supervision at the Department of Mechanical Engineering, Faculty of Engineering, University of Kerbala as a partial of fulfilment of the requirements for the Degree of Master of Science in Mechanical Engineering.

Signature: *A. M. Al-Hamood*

Dr. Amjad Al-Hamood

Date: 5/5 / 2024

Linguistic certificate

I certify that the thesis entitled "**Simulaion And Multibody Dynamic Analysis of a Cam Based Infinitely Variable Transmission**" which has been submitted by **Minyar Hamdi Almullahassan** has been proofread, and its language has been amended to meet the English style.

Signature:



Name:

Ali Basem M. Ali

Date: 13/12/2023

Abstract

Continuously variable transmission (CVT) is a system that allows for smooth continuous change of transmission ratio between two driver and driven elements. A CVT is a subset of IVT; Infinitely Variable transmissions which can produce smooth transmission ratio including zero value. These are in contrast to traditional transmissions which typically have a discrete and limited number of transmission ratios or as commonly known as gear ratio. CVTs are started to be alternatives to the traditional gear trains in vehicles, as they can provide smoother acceleration and better fuel economy.

In this thesis, a cam based IVT is studied in details utilizing theoretical analysis and simulation model. In the current IVT contains two units, each unit consists of a cam, a follower, alterable slotted link, grooved wheel and a grooved wheel actuator. The selected cam profile consists of two parts which are constant velocity which represents forward stroke and polynomial for the return stroke, this will be investigated in this study.

The simulation of the system in the current study is carried out using Matlab Simscape software where the theoretical analysis is used to validate this simulation model. By using Matlab Simscape software, the geometry of each element should be constructed in details. Then, these elements are assembled using available specific joints depending on the actual joints in the systems. The locations of these elements or joints should also adjust using local frames and rigid transform in order to match them with the global system frames.

The results show that a smooth variation in output can be achieved for various positions of the transmission ratio alterable. However small jump in the output can be noticed during stroke change while the alterable is moving. This can be solved by

adding a flywheel to the system. It can also be concluded that the vertical position and velocity of the alterable has a significant effect on the system output.

Undertaking

I certify that the research work entitled “**Simulation and Multibody Dynamic Analysis of a Cam Based Infinitely Variable Transmission**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Signature:



Minyar Al-Mullahassan

Date: 7/5/2024

Dedication


First I'm very thankful to my ALLAH by finishing this work after a hard time passed

To that distant, close person who lives in my heart and causes my inner peace, and whose presence I was hoping for today

I would like to dedicate this work to my mother, who has been supportive and helpful to me, as well as my wife did

I would like to dedicate and thank my supervisor, Dr. Amjad, who was the main supporter along the way, and his advice and guidance had a positive impact on the work.

I also thank my friends who supported me during my work period

Signature: 

Minyar Al-Mullahassan


Date: 7/5/2024

Acknowledgements

I would like to thank the head of the department of mechanical engineer for his helpful advices for this work

Also the whole staff in the the department represented by an elite of professors was very kind and they keep encourage us during this work

Finally I would like to thank my supervisor who stands by me during this time of work

Signature:  XX

Minyar Almullahassan

Date: 7/5/2024

List of contents

<u>Examination committee certification</u>	iii
<u>Supervisor certificate</u>	iv
<u>Linguistic certificate</u>	v
<u>Abstract</u>	vi
<u>Undertaking</u>	viii
<u>Dedication</u>	ix
<u>Acknowledgements</u>	x
<u>List of Contents</u>	xi
<u>List of Tables</u>	xv
<u>List of Figures</u>	xvi
<u>List of Abbreviations</u>	xx
<u>List of Symbols</u>	xxi
<u>Chapter One: Introduction</u>	1
<u>1.1 General</u>	1
<u>1.2 Continuously variable transmission(CVT)</u>	2
<u>1.3 Types of continuously variable transmission</u>	2
<u>1.3.1 Transmission with Continuously Varying Traction</u>	2
<u>1.3.1.1 Belt Driven Pulley Size Adjustment (VDP)</u>	2
<u>1.3.1.2 Toroidal CVTs</u>	4
<u>1.3.2 Non-traction CVT Ratio</u>	5
<u>1.3.2.1 Transmission Link Capable of Infinite Variation (IVT)</u>	5

1.3.2.2	<u>Infinitely Variable Transmission Using a Cam System</u>	6
1.3.2.3	<u>Infinitely Variable Drive (IVD)</u>	7
1.4	<u>CVT Applications in Power Plants</u>	8
1.4.1	<u>Wind Turbines</u>	8
1.5	<u>Objective</u>	9
<u>Chapter Two: Literature review</u>		11
2.1	<u>Introduction</u>	11
2.2	<u>Traction IVT syetems</u>	12
2.2.1	<u>Toroidal CVTs</u>	19
2.2.2	<u>Diameter of the Pulley Can Be Changed (APD)</u>	20
2.3	<u>Non-Traction IVT systems</u>	23
2.4	<u>Concluding Remarks</u>	26
<u>Chapter Three: Theoratical and simulation analysis</u>		27
3.1	<u>Introduction</u>	27
3.2	<u>Cam profile</u>	28
3.2.1	<u>Constant-constant profile</u>	28
3.2.2	<u>Constant-polynomial(1-5) profile</u>	30
3.3	<u>Alterable slotted link</u>	31
3.4	<u>Grooved Wheel followers</u>	32
3.5	<u>Boundary conditions</u>	33
3.6	<u>Ratchet</u>	36
3.7	<u>Simulation part</u>	37
3.7.1	<u>Introduciton</u>	37

3.7.12	<u>MATLAB Simscape</u>	37
3.8	<u>Simulation model</u>	39
3.9	<u>Input and output</u>	41
3.10	<u>System parameters</u>	44
3.11	<u>Mechanism parts and operation</u>	44
3.11.1	<u>Mechanism parts</u>	44
3.11.1.1	<u>Cam shaft</u>	46
3.11.1.2	<u>Cam follower</u>	47
3.11.1.3	<u>Alterable slotted link</u>	48
3.11.1.4	<u>Grooved wheel actuator</u>	49
3.11.1.5	<u>Grooved wheel shaft</u>	50
3.11.1.6	<u>Ratchet</u>	51
3.11.1.7	<u>Main body</u>	51
3.12	<u>System operation</u>	53
3.13	<u>The whole system block diagram</u>	53
<u>Chapter Four: Results and discission</u>		57
4.1	<u>Introduction</u>	57
4.2	<u>Theoretical & simulation results</u>	57
4.2.1	<u>Constant – constant cam profile</u>	57
4.2.2	<u>Constant – Polynomial cam profile</u>	60
4.3	<u>Alterable slotted link</u>	62
4.3.1	<u>constant velocity – constant veolcity cam profile</u>	62
4.3.2	<u>constant velocity – polynomial cam profile</u>	64
4.4	<u>Output results based on fixed alterable position</u>	66

4.4.1	<u>Single unit results</u>	66
4.4.2	<u>Two units results</u>	69
4.5	<u>Output results based on moving alterable position</u>	71
4.5.1	<u>Single unit results</u>	71
4.5.2	<u>Two units results</u>	73
<u>Chapter Five: Conclusions and future works</u>		75
5.1	<u>Conclusions and remarks</u>	75
5.2	<u>Recommendations and future works</u>	76
<u>References</u>		77

List of Tables

Table 3-1: Six constants of polynomial equation.....	34
--	----

List of figures

<u>Figure 1-1: CVT (pulley with a changing diameter)</u>	3
<u>Figure 1-2: Metal belt</u>	4
<u>Figure 1-3: Principal element for a toroidal CVT</u>	4
<u>Figure 1-4: Transmission with both complete and partial toroidal</u>	5
<u>Figure 1-5: The primary components of the gearbox with infinite range (IVT)</u>	6
<u>Figure 1-6 The principal components Infinitely Variable Transmission Using a Cam System</u>	7
<u>Figure 1-7: The Drive with Unlimited Variability (IVD)</u>	8
<u>Figure 1-8: CVT usage in wind power</u>	9
<u>Figure 2-1: The first patent on the toroidal CVT</u>	13
<u>Figure 2-2: Half toroidal CVT by Wright Aeronautical</u>	14
<u>Figure 3-1: Current infinitely variable transmission system (IVT)</u>	27
<u>Figure 3-2: Operating of a single unit of constant-constant cam profile</u>	28
<u>Figure 3-3: Displacement, velocity and acceleration for Constant Velocity profile</u>	30
<u>Figure 3-4: Combined cam profile (constant velocity-polynomial)</u>	35
<u>Figure 3-5: Forward and Backward strokes displacement, speed, and acceleration for a cam with a constant velocity-polynomial profile</u>	36
<u>Figure 3-6: Icon of MATLAB, Simulink & Simscape</u>	38
<u>Figure 3-7: Schematic diagram presenting followers and slotted link</u> .	39
<u>Figure 3-8: Prismatic joint & scope</u>	40
<u>Figure 3-9: Prismatic joint parameter window</u>	40
<u>Figure 3-10: Types of inputs</u>	41
<u>Figure 3-11: Signal editor window</u>	42

<u>Figure 3-12: Signal editor window (cam followers motion)</u>	42
<u>Figure 3-13: Types of outputs</u>	43
<u>Figure 3-14: System settings</u>	44
<u>Figure 3-15: Simulated mechanism front veiw</u>	45
<u>Figure 3-16: Simulated mechanism side view</u>	46
<u>Figure 3-17: Cam shaft</u>	47
<u>Figure 3-18: Cams follower</u>	48
<u>Figure 3-19: Alterable slotted link</u>	49
<u>Figure 3-20: Grooved wheel actuator</u>	50
<u>Figure 3-21: Grooved wheel shaft</u>	51
<u>Figure 3-22: Main body</u>	52
<u>Figure 3-23: Full system simulation</u>	54
<u>Figure 3-24: Main body & simulation parameter</u>	55
<u>Figure 3-25: Input shaft</u>	55
<u>Figure 3-26: Output shaft</u>	55
<u>Figure 3-27: Unit one</u>	56
<u>Figure 3-28: Unit two</u>	56
<u>Figure 4-1: Displacement of Theoretical and simulation of Constant-Constant cam profile</u>	58
<u>Figure 4-2: Velocity of Theoretical and simulation of Constant-Constant cam profile</u>	59
<u>Figure 4-3: Acceleration of Theoretical and simulation of Constant-Constant cam profile</u>	59
<u>Figure 4-4: Displacement of theoretical and simulation of constant polynomial cam pofile</u>	61
<u>Figure 4-5: Velocity of theoretical and simulation of constant polynomial cam pofile</u>	61

<u>Figure 4-6: Acceleration of theoretical and simulation of constant polynomial cam profile.....</u>	<u>62</u>
<u>Figure 4-7: Angular displacement of alterable slotted link for two units.....</u>	<u>63</u>
<u>Figure 4-8: Angular velocity of alterable slotted link for two units.....</u>	<u>63</u>
<u>Figure 4-9: Angular acceleration of alterable slotted link for two units.....</u>	<u>64</u>
<u>Figure 4-10: Angular displacement of alterable slotted link for two units.....</u>	<u>65</u>
<u>Figure 4-11: Angular velocity of alterable slotted link for two units.....</u>	<u>65</u>
<u>Figure 4-12: Angular acceleration of alterable slotted link for two units.....</u>	<u>66</u>
<u>Figure 4-13: Three output displacements for the same input for single unit.....</u>	<u>67</u>
<u>Figure 4-14: Three output velocities for the same input for single unit.....</u>	<u>68</u>
<u>Figure 4-15: Three output accelerations for the same input for single unit.....</u>	<u>68</u>
<u>Figure 4-16: Input and output displacements for two units at particular alterable vertical position (7cm).....</u>	<u>69</u>
<u>Figure 4-17: Input and output velocity for two units at particular alterable vertical position (7cm).....</u>	<u>70</u>
<u>Figure 4-18: Input and output acceleration for two units at particular alterable vertical position (7cm).....</u>	<u>70</u>
<u>Figure 4-19: Three output displacements for the same input for single unit.....</u>	<u>71</u>

Figure 4-20: Three output velocities for the same input for single unit.....72

Figure 4-21: Three output accelerations for the same input for single unit.....72

Figure 4-22: Two units output displacements for the same input.....73

Figure 4-23: Two units output velocity for the same input.....74

Figure 4-24: Two units output acceleration for the same input.....74

List of Abbreviations

Abbreviations	Description	Units
CVT	Continuously Variable Transmission	-
IVT	Infinitely Variable Transmission	-

List of symbols

	Symbol	Description	Units
1	C_i	Constant of proportional	-
2	r_b	Cam Base circle	mm
3	ω_i	Angular velocity of the cam	rad/s
4	ω_o	Angular velocity of grooved wheel	rad/s
5	x_i	Displacement of Cam Follower	mm
6	\dot{x}_i	Velocity of the cam follower	mm/s
7	\ddot{x}_i	Acceleration of the cam follower	mm/s ²
8	x_o	Displacement Grooved wheel actuator	mm
9	\dot{x}_o	Velocity of the grooved wheel actuator	mm/s
10	\ddot{x}_o	Acceleration of the grooved wheel actuator	mm/s ²
11	y	length of the slotted link, equal 200 mm	mm
12	y_i	Length arm at side input for slotted link	mm
13	y_o	Length arm at side output for slotted link	mm
14	y	length of the slotted link, equal 200 mm	mm
15	θ_i	Angular displacement of input Shaft	rad
16	$\dot{\theta}_i$	Angular velocity of input Shaft	rad/s
17	$\ddot{\theta}_i$	Angular acceleration of input Shaft	rad/s ²
18	θ_o	Angular displacement of output Shaft	rad
19	$\dot{\theta}_o$	Angular velocity of output Shaft	rad/s
20	$\ddot{\theta}_o$	Angular acceleration of output Shaft	rad/s ²

CHAPTER ONE: INTRODUCTION

1.1 General

In most cases it is not possible to directly transfer the power and torque produced by the supplies of energy (such as automotive engines, turbines for windmills, or any other type of energy source) for use in applications. Due to this, transmission for shaft was discovered. For instance, the variable input (wind speed) in a wind turbine must be altered such that the exit axle rotates at a consistent speed. In order to provide the appropriate level of electrical power characteristics. Flexible front, rear, low fuel consumption, neutral movement, passenger and driver comfort are all demands placed on gearboxes, whether they are manual or automated.

The researchers discovered that the traditional transmissions mentioned above (manual and automatic) are complicated, bulky, and relatively expensive. It is better to use a more reliable one for these reasons. Therefore, it is advised to use continuously variable transmission (CVT) in its place. CVTs allow step less speed ratio changes between rotating parts. However, gear boxes use discrete shifting to obtain variable gear ratios. CVTs with IVT technology (CVT system) can use a zero-transmission ratio and are very variable.

Wind and water turbine engineers utilize CVT instead of conventional gearbox methods to match the power source's variable speed with the generator's fixed rotating speed. Thus, the required power voltage and frequency are reached. CVT transmissions are replacing conventional gears in the car sector. The CVT keeps the engine and wheels in sync when changing gears. This makes engine loading quiet and the ride comfortable. Gear shifting reduces engine power loss, lowering fuel consumption and emissions. The IVT mechanism is a CVT that

facilitates the transfer of rotational motion between two spinning components, enabling the generation of continuous transmission ratios without discrete steps, including the possibility of a zero value

1.2 Continuously Variable Transmission (CVT)

The transmission ratio among spinning inputs also outputs one positive value to one more can be gradually altered using continuously variable transmission (CVT) [1]. A choice of gears is not constrained to a limited range of ratios, in contrast to conventional transmissions. One kind of infinitely variable transmission (IVT) that has a transmission ratio of zero for all potential variations is a continuously variable transmission (CVT)[2]. In light of the foregoing debate, automakers and auto businesses strive to acquire a power transmission that meets certain requirements (it is simple, affordable, and more efficient than conventional power transfer). Due to this, the variable diameter pulley-based IVT, which uses specialized belts to transfer power, was created. This type of IVT shares similarities with Milton Reeves power transmission systems, which were developed at the start of the 20th century, thanks to its multiple gear ratio advantage. The following sections detail the operation of a V-belt and various types of continuously variable gearboxes.

There will be a 3% decrease in fuel consumption (compared to manual and classic automatic transmissions) when medium-sized cars and machinery use CVTs [2].

1.3 Types of continuously variable transmissions

The two types of CVT transmissions that make up the majority are generally:

1.3.1 Transmission with Continuously Varying Traction

1.3.1.1 Belt Driven Pulley Size Adjustment (VDP)

The continuously variable gearbox (CVT) type discussed is widely utilized in various applications. Based on the data presented in Figure 1.1, it is possible to modify the diameter of the pulleys in order to adjust the speed ratio. The primary reason for this phenomenon is the limited number of elements involved, which enables the attainment of a broad spectrum of rotational speed ratios without the necessity of employing complex components. Two factors that require careful consideration are the preservation of tension value in a belt conveyor capacity and the maintenance of the distance between the pulley axles. The essential elements of this continuously variable gearbox (CVT) are:

- 1- Belt of transmission
- 2- Variable diameter pulley for the driver shaft
- 3- Changeable diameter pulley for the driven shaft
- 4- Simple control system

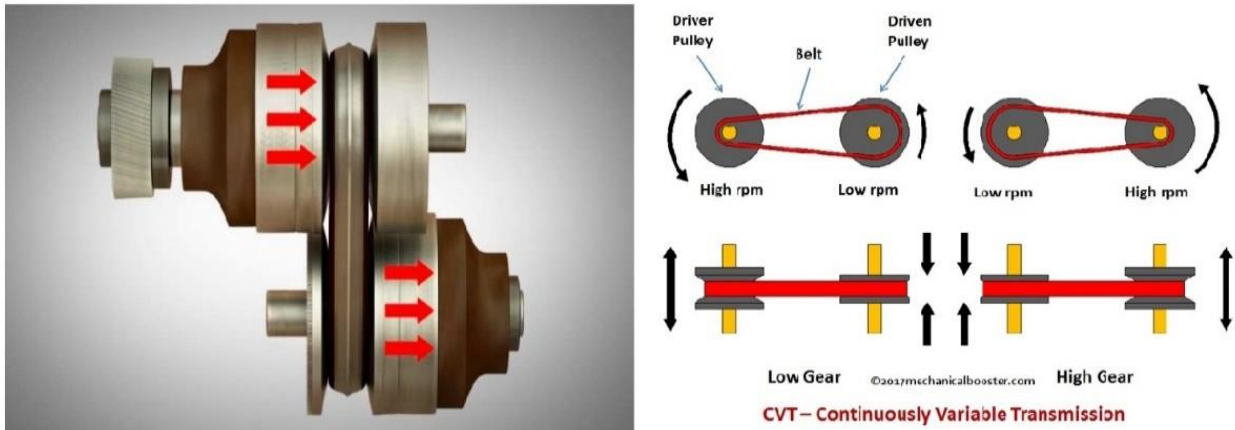


Figure (1-1) CVT (Pulley with a Changing Diameter) [11]



Figure (1-2) Metal belt [11]

1.3.1.2 Toroidal CVTs

This kind is utilized with machinery and systems that require a medium torque. The V-belt style likewise uses straightforward parts, See figure (1:4).

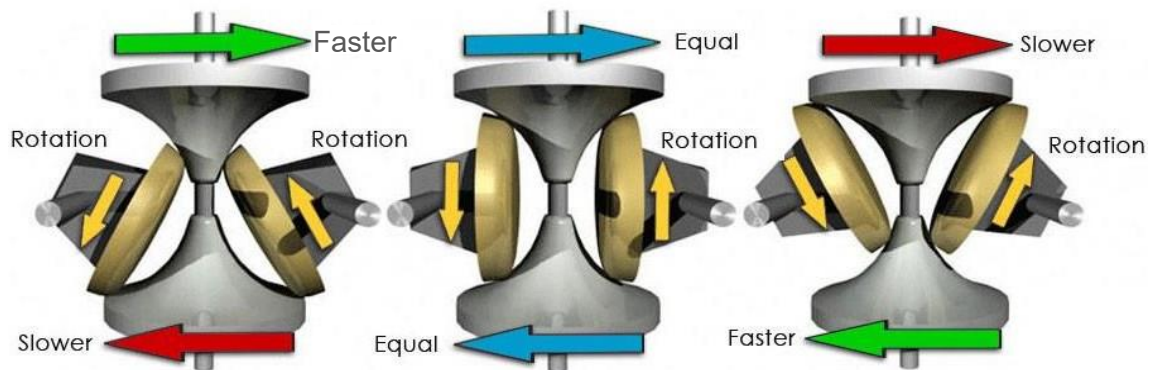


Figure (1-3) Principal element for a toroidal CVT [11]

This mechanism works as follows :The power supply is connected to one of the discs, and the output is considered to be the other disc. The location of the roller, which serves as the transmission medium, is changed to produce different speed

ratios. The ability of the utilized oils to shear to lubricate the gearbox serves as the power transfer mechanism instead of the friction between the surfaces. There are two different categories for this type. Full toroidal, and half toroidal. Figure 1.5 [5] shows that the second type differs from the first in that it is more effective, capable of transporting a greater capability, and occupies less space.

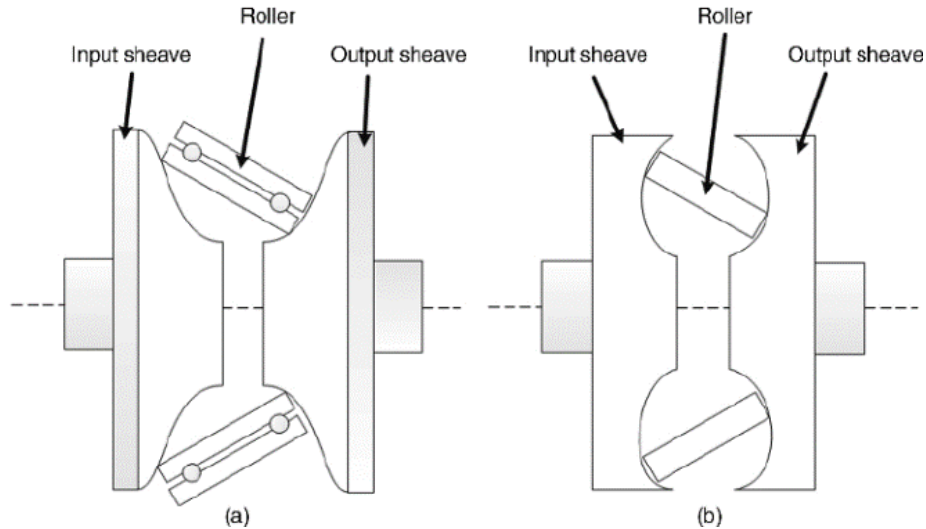


Figure (1-4) Transmissions with both complete and half toroidal CVT [11]

1.3.2 Non-traction CVT Ratio

1.3.2.1 Transmission Link Capable of Infinite Variation (IVT).

Figure (1-5) illustrates this mechanism's fundamental design. Because they don't rely on friction for power transmission, the non-traction varieties have the main advantage of transferring more power. High reliability and ease of installation are other benefits of this mechanism. The mechanism works in the manner described below. The free shaft, which acts as a self-adjusting spring, converts the spinning speed into an oscillating velocity in the follower. The one-way clutch transmits the reciprocating motion to the planetary gear set, converting the intermittent reciprocating speed to a continuous rotational speed. The advantages of this technology in the context of a wind turbine include its low weight, ease of

manufacture and maintenance, and relative simplicity of installation. The loaded phase is denoted by mode A, and the unloaded phase is denoted by mode B.

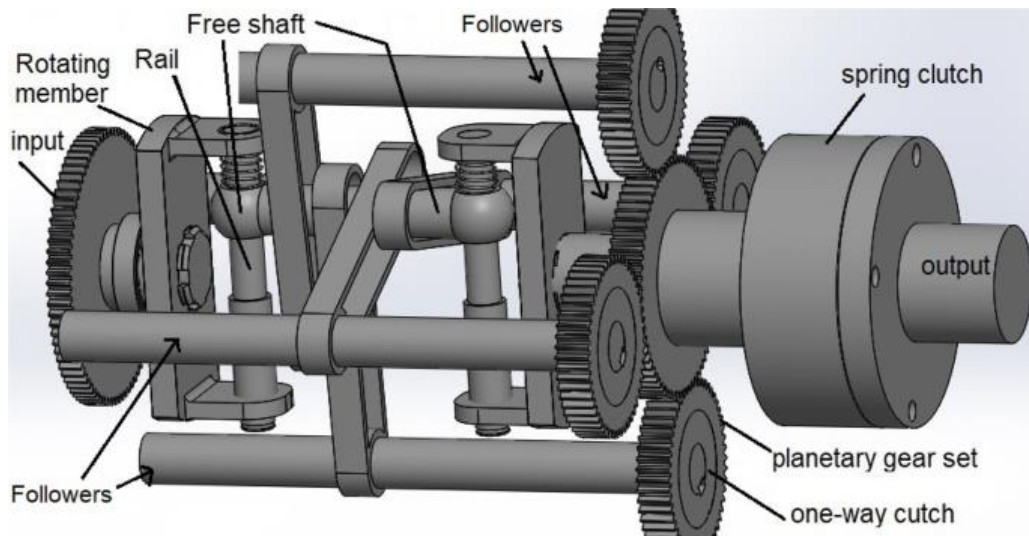


Figure (1-5) The primary components of the gearbox with infinite range (IVT) [11]

1.3.2.2 Infinitely Variable Transmission Using a Cam System

The followers of this form of Cam-based Infinite variable are driven by a 3D cam, as opposed to the previous IVT type, which is comparable in some ways. As shown in figure (1-6). Contrary to the preceding device, which naturally organizes itself, the follower position is altered to achieve different speed ratios by a specific external mechanism. The key components of this device are the sun gear, planet gear, followers, one-way clutch, and 3D cam. In terms of the mechanism's motion, the size and form of the cam determine how the follower is propelled, organizing the rotational motion with a rotational frequency movement. In order to produce a positive rotational speed, the rotating movement is transmitted to a (unidirectional clutch). The planet gear and sun gear, also known as the output shafts, are where the spinning motion is received. The speed of the follower is reduced to zero by mounting it on an asymmetric (cam) surface around the axis of rotation. The uniqueness of this type lies in its infinite potential for speed ratios. Stress on the cam

and follower contact surfaces limits the amount of power that can be communicated [2].

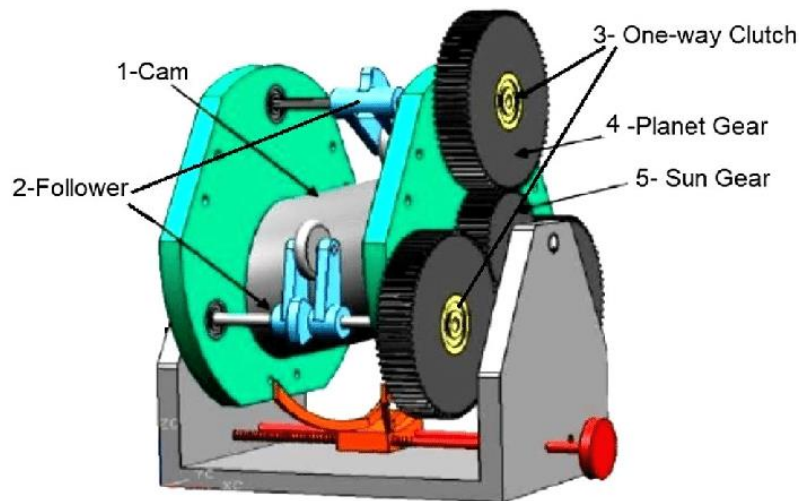


Figure (1-6) The principal components of Infinitely Variable Transmission Using a Cam System [11]

1.3.2.3 Infinitely Variable Drive (IVD).

The parts for a (IVD) CVT are depicted in Figure 1-7. Some examples are the frame one-way clutch push link input shaft slant plate bevel gear set, an output shaft, and slant plate. The steps involved in the process can be summarized as follows:

- 1- The input shaft receives energy from the source and rotates at a consistent speed.
- 2- Using a tilting plate, the continuous rotating speed is converted into frequency. The sloping plate's angle of inclination can be adjusted as needed; for example, if zero velocity is desired in an output shaft, an angle will be zero. The angle value needs to be bigger in order to enhance the velocity.

- 3- The push link's reciprocating motion is transmitted from the tilting plate via a spherical joint. This multiparty allows for movement along three axes (x, y, z). The push link has this joint at both ends.
- 4- The one-way clutch, which only transmits power or angular velocity in the positive section, receives a reciprocating movement beginning the push link. Use six one-way clutches to increase the device's angular velocity stability. The output shaft is connected to a bevel gear set that includes a bevel gear 3-driven gear in order to transmit the speed or frequency displacement. Finding the output speed by using a planetary gear system [1].

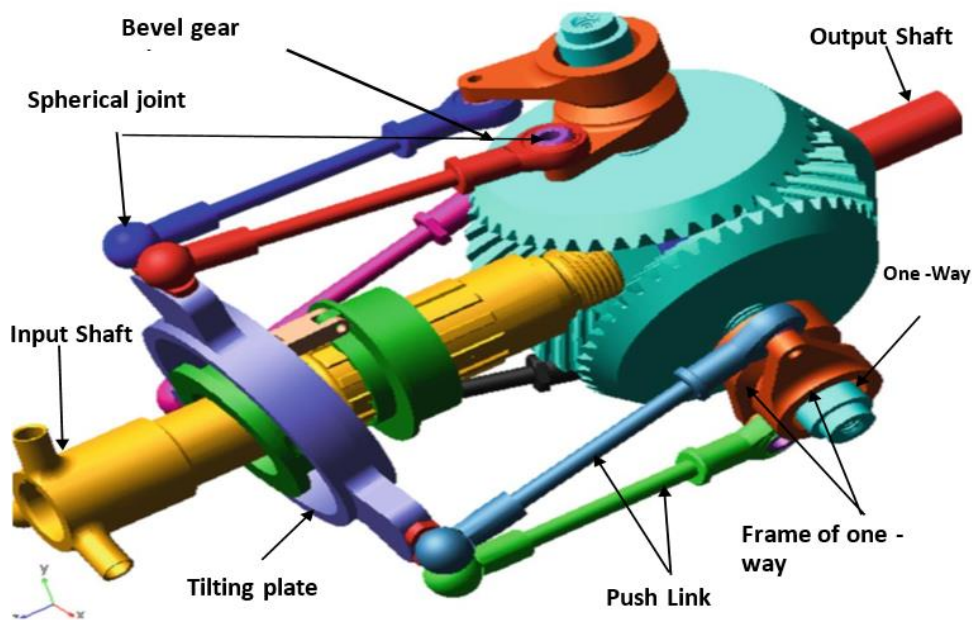


Figure (1-7) The Drive with Unlimited Variability (IVD) [11]

1.4 CVT Applications in Power Plants

1.4.1 Wind Turbines

The quantity of energy obtained from the wind in wind turbine applications is achieved by the turbine rotor, wherever the quantity of this energy is

dependent on the velocity of the wind. The frequency of electricity can be controlled using a variety of electrical base technologies to accommodate varying wind speeds. Besides electrical technologies, mechanical technologies in generators use conventional gearboxes or continuously variable transmissions (CVT) to operate at a fixed speed on one side of the generator and variable speed in accordance with the wind speed on the opposite side. With the help of a unique control system and the advantages of this technology, the generator may run at a fixed frequency while maintaining a constant speed [10]. As shown in figure (1-8)

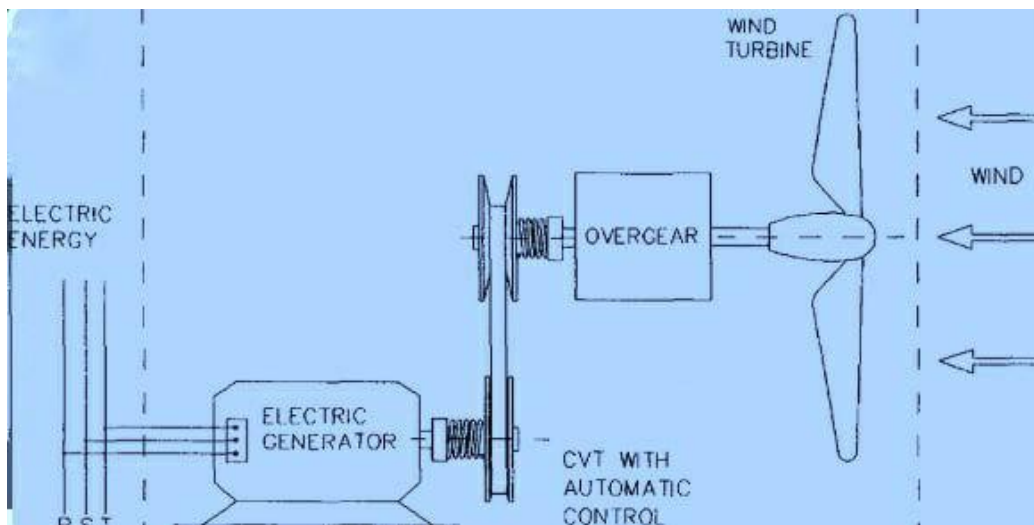


Figure (1-8) CVT usage in wind power [11]

1.5. Objective

The Infinitely Variable Transmission (IVT) is a mechanism that facilitates the transfer of rotational motion between two spinning components, enabling the generation of continuous transmission ratios without discrete steps, including the possibility of a zero value. The objectives of this thesis include:

- 1- A theoretical model based on the geometric analysis of a cam based IVT is constructed.
- 2- A simulation model is developed utilizing the MATLAB Simscape Simulink

for modelling the IVT system selected.

- 3- The two models (theoretical and simulation) are used in order to validate each other.
- 4- A parametric study of the IVT system is carried out using the constructed models especially the simulation model.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Significant scientific effort has been made in the previous two decades towards creating transmissions for vehicles that use less energy overall. One of the most vital critical attributes of a passenger is a good ride-performance vehicle. One strategy to do this is to use continuously variable transmission. The range of gears offered by a continuously variable transmission (CVT) is wide. ratios between the specified limits, improving the fuel economy also dynamic performance of a vehicle through more closely coordinating the engine's operation with the different driving situations. The car industry is typically the first to employ IVTs. This is being done to satisfy both the comfort of the passengers and the driver. In addition to being easy to install and maintain, some varieties of IVT do not require a clutch, as was previously indicated. The energy input to wind or water turbines is not constant. The benefit of constant speed in output axis is something IVT can offer. This is the element that will help you achieve a steady frequency [2]. In the year 1490, *Leonardo de Vinci* drew his conceptualization of the IVT. The history of IVTs in automotive applications dates back to the early stages of automobile development, and Definitely during the same time span as traditional automatics. General Motors created a fully toroidal IVT in the early 1930s and put it STHROUGH rigorous testing before electing to implement a standard stepped-gear automatic out of economic considerations. General Motors IVT's research was revived in the 1960s, although none were ever produced. For a number of years, a smaller automobile from British manufacturer *Austin* included a IVT, but it was eventually discontinued due to the CVT's expensive cost, low dependability, and insufficient torque transmission. Early CVTs frequently employed a straightforward rubber band in addition come mechanism, similar to one created by the Dutch company Daf in 1958.

Daf's IVT, however, could first manage a 0.6L engine, too serious issues by noise besides harsh riding ultimately damaged its image. However, in the early 1990s, an electromechanical IVT based on a dry hybrid rubber belt was used for motorcycles. The electromechanical IVT grounded on a metal belt is not yet commercially accessible. Today, the steel push belt produced by the van Doorne firm is used as the transmission component in practically all IVTs on the market. In 1987, this steel-pushing belt made its debut. The proposed work was compared with the previous studies by reviewing a body of literature.

2.2. Traction IVT systems

2.2.1 Toroidal CVTs

The concept of the toroidal IVT was first developed by Charles W. Hunt of Richmond, New York, in the United States. U.S. patent 197 472 was issued on November 27, 1877, and it describes his idea. An oscillating wheel (E) is positioned between disks B and D in the patent's illustration figure 2.1. Speed can be altered by changing the angle of this wheel. Disks B and D have spherical surfaces. Due to this structure's extreme simplicity, industrial use was considered. In the 1920s, numerous samples were produced and marketed after the applicability of automotive transmissions was studied with the advent of automobiles. Even though it didn't find much commercial success, a car with such a technology was created and was dubbed a "friction drive car."

The half toroidal IVT was later developed by Wright Aeronautical in 1943. In 1959, Wright obtained a patent from Charles E. Kraus and created the IVT seen in figure 2.2. Numerous bench tests on real cars were performed. Kraus emphasized that decreasing the spin at the power-transmitting contact point not only expands the contact point surface but also improves transmission endurance and efficiency while

also reducing size. In a Ford Pinto with 85 HP, Charles Kraus and his son James tested a traction drive CVT in 1973 at Traycall, Texas. The FVT's transmission ratio ranged from 2.65:1 to 0.6:1 at that time (transmission ratio range 4.417). They predicted that the CVT will be able to achieve good acceleration, great fuel efficiency, and better car emissions based on the findings of this test. Applying the lessons from the Oil Shock and taking Professor Tomoo Ishihara's (Institute of Industrial Science, University of Tokyo) suggestion that automatic transmission would switch to the CVT due to its higher fuel efficiency into consideration, NSK Ltd. began research and development on the half toroidal CVT in collaboration with Professor Ishihara's research team in 1978.

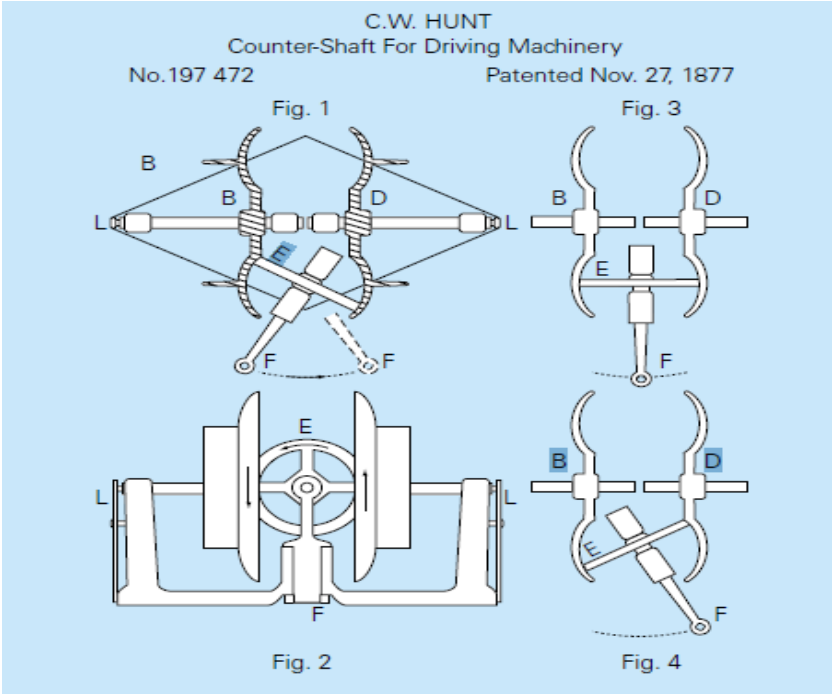


Figure (2-1) The first patent on the toroidal CVT

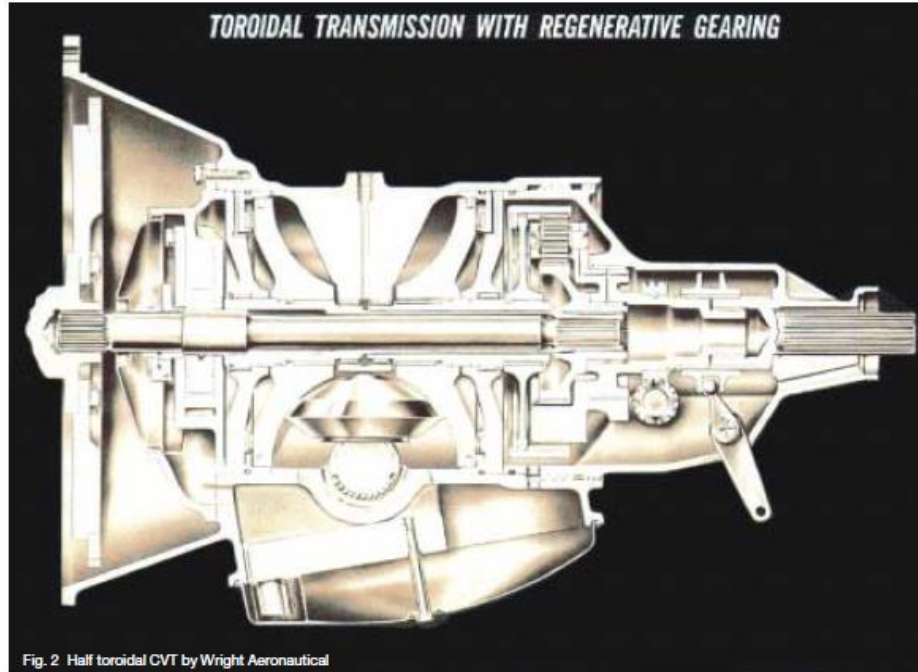


Figure (2-2) Half toroidal CVT by Wright Aeronautical

The following characteristics of a double-cavity IVT power transmission system was described by Tanak et al. (1995) [1] a radius of 40mm, the distance among the two centers of a toroid. The test parameters were 7000 rpm, 340 Nm of torque, and 3.2 kHz of oil pressure between the surfaces. It was determined that the oil pressure in the contact region hits 2.7Hz when fatigue reaches its peak value. At an oil pressure value of 3 kHz, the maximum stress limit is reached. The slow rotation of the device's components, which ranges from 0.44 to 2.28, results in improved efficiency and transmission speed because it produces less heat.

The mechanical components of the annular IVT were briefly explained in a new model of the device made by Belfiore et al. (2003) [2]. The device's special structure was also subjected to a mechanical study. In order to limit slippage in the contact areas, two angles were used in the mechanical analysis. The device could produce ratios that were endlessly quick, according to the conclusions of the theoretical analysis. The mechanism of control is based on the values of two angles

(θ also α) that result in motion without sliding. Theoretical research on static forces led to the discovery of the largest transferable torque, which is 30 N.m.

A comprehensive analysis of a steady-state behavior of the full half toroidal IVTs is included in the study by Carbone et al. (2004) [3]. The findings of that study indicated that, across the board, half-toroidal IVT performed better than complete toroidal. Major causes of the reduced efficiency are increased spin and losses due to a higher slide. The lack of consideration for dynamic conditions is a weakness of this analysis. However, the IVT is employed with a variable speed ratio in automotive and wind power applications. Therefore, it is essential to focus on these changing conditions.

Although Wang et al. (2014) [4] While a new power transmission method (Toroidal-IVT) has been investigated, the mechanism for sending power or torque to the outlet axis remains unproven (a sphere installed on a shaft via a universal joint). When compared to (Toroidal-IVT), which is considered one of the (Toroidal) types, it was found that the device, despite its ability to change ratios, was not especially good at transferring torque.

The traction-driven toroidal continuously variable gearbox is an alternate design option; it often employs specialized hydraulics or an adaptive cam-based mechanism to regulate power output in real time. Two discs (input and output) come into contact with a number of rollers whose inclination determines the speed ratio, and the contact between the discs and the rollers is lubricated to prevent friction. Wind energy gathering at low power levels is one example of a practical application. Tyreas et al. (2016) [5] describe such setups, in which a wind turbine is connected to a generator that supplies electricity to a utility.

Verbelen et al. (2017) [6], define a method for determining the most efficient and effective speed ratio variation with respect to ratio variation speed (dynamics). The algorithm was originally designed for toroidal IVTs but it may be used for both. The algorithm is a natural choice for this paper's comparison, as its goal is to examine a dynamic action of mutually exclusive variants while also considering an efficiency during relation difference. The primary innovation of this work is the comprehensive analysis of dynamic behavior overall operating ranges, comparing the two topologies. In Verbelen study, he use the concept of relative velocity changes to define dynamic behavior. Variations in efficiency during these dynamic events, as well as the time required to adjust the speed ratio by a fixed amount, are discussed. Several technology-agnostic design concepts that affect the continuously variable transmission's (IVT) dynamic behavior are proposed as a result of this research.

Theoretically, full and a half (IVT) was compared by Verbelen et al. (2018) [7] under dynamic loading. In these conditions, the running range-based IVT's effectiveness is assessed. According to the findings, the (IVT half) is more effective during loading (IVT full). In other words, even when the ratios change abruptly, high torque can be transferred at both high and low speeds thanks to the device's (IVT half), which works exceptionally well.

Milazzo et al. (2020) [8] investigated the potential application of self-controlled IVT that operates on a like but simpler concept towards the (IVT-full-toroidal). Wind turbines, motorcycles, and bicycles are just a few examples of machines that could benefit from using the fewer parts now accessible. Using the CATIA program and taking into account variables like wind speed and temperature typical to Italy, the researcher created a simulation model. No external pressures are needed to counteract the model's inherent inertia torque forces, it was discovered.

In their investigation of IVT, Marathe and Wakchaure (2020) [9] focused on the Single Ball Traction Drive. They offered a workable model that could anticipate a range of transition speeds. The device's novel (IVT-toroidal) functioning mechanism allowed for its simplicity and inexpensive cost. They came to the following conclusions based on their practical experience and the information they gathered:

- 1- It was possible to make (step-less) adjustments to the speed ratios among the entry and exit axes.
- 2- little in stature and cheap to boot.
- 3- The device can achieve an impressive efficiency of 75%.
- 4- Jerk (single ball) should be utilized if you want a silent machine (no shock when adjusting the ratios).
- 5- When employed in mechanical applications, a unique method is required to modify transfer ratios.
- 6- Ability and productivity are inversely related.

Nike et al. (2021) [10] In this article, the gearbox system of the car's powertrain adjusts the gear ratios. The pulley-type CVT system is the subject of this study. The optimization of a continuously variable transmission's torque ramp angle and wedge angle is the main topic of this study. Based on the graphs, it can be deduced that the torque increases with the angle of inclination, increasing the force component opposing the primary pulley's turning force and increasing the duration.

Cote and Latas (2021) [11] researched the results of vibration tests conducted on a continuously variable transmission (IVT) connected to a two-stroke internal combustion engine. Utilizing a high-speed camera, measurements were taken. An equation for the nonlinear partial integral differential of the moving belt's vibrations is provided. A simplified linear equation is used to describe the observed impacts on the amplitude and frequency characteristics of the measurements. The speed of the

conveyor belt at which the echo occurs can be calculated using an approximation of a formula.

In this study, Yukawa et al. (2022) [12] described a continuously variable gearbox (IVT) comprised of couplings cranks cams and freewheels. The IVT transmission's input and output shafts are coupled in parallel by each unit, which has a slider crank mechanism affixed. In a IVT system, the output shaft rotates continuously in response to the input shaft's continuous rotation input independent of the arbitrary gear ratio, and the output shaft rotates in proportion to the input shaft's rotational speed with respect to the arbitrary gear ratio. The sliding crank mechanism used in a IVT gearbox is modelled mathematically in this paper's conclusion. He pay special attention to the geometry of the connection between the correlation mechanisms and the 3D cam. Since this coupling mechanism does not consist of frictional components, it provides high transmission efficiency.

In this work, Faleh et al. (2022) [13] An IVT is a vector whose ratio of two rotating components has an indefinite (i.e., non-discrete) variance (including zero). In this tutorial, a cam-based IVT system is built also modeled using SolidWorks software. The system under investigation consists of two similar units. A swing-aperture camera is built into each device; It can be tilted on a hinge and moved vertically by altering the frequency of transmission. The output shaft (ratchet) is moved in one direction by a one-way clutch that is coupled to the elevated wheels' oscillating rotary motion. For the sake of the present study, a combination of univariable velocity and polynomial forms 1 through 5 was specifically created. The simulation's output generally confirms the results predicted theoretically given the current IVT system configuration. The findings suggest that each unit should be powered at a constant pace for all sections in it. The output axis' angular velocity in

this study, however, exhibited discernible oscillations due to the ratchet that was employed.

2.2.2 Diameter of the Pulley Can Be Changed (APD)

Mangialardi and Mantriotn (1992) [14] used mathematical analysis to discuss the feasibility of installing a (IVT) device among a wind turbine in addition a generator. It is known that a mechanical power source with constant rotation also torque is required to generate electricity, and it is also common knowledge that the operating circumstances for a wind turbine are invariably unstable, both of which point to the need for a continuously variable gearbox. Both electronic gadgets and adjusting the step angle of wind turbine blades were considered. However, the equipment utilized in the first two options is thought to be too costly for most people. The addition of a continuously variable gearbox (CVT) to a wind turbine has been found to improve the turbine's efficiency while also providing stable frequency and voltage. In most cases, it raises efficiency.

Mangialardi and Mantriota (1994) [15] used mathematical typical to compare performance of wind turbines with IVT-type transmissions also those with conventional power transmission (gearbox). This data comes from actual workplace settings. This is what the study's author concluded. The implementation of IVT described in this study reduces costs while increasing dependability in the transmission of power with few moving parts. It has been found that the output of electrical power from wind turbines (IVTs) is maximized in the presence of strong winds.

Chen et al. (1998) [16] directed a field study towards measure torque, speed, and power losses in the IVT type while operating in different situations. The study focused on the exterior sizes of the pulley and the load as they were affected by the following test conditions: rotational speed, speed, change ratios, also tension in a

belt conveyor for power. A Power gearbox of the type (V Belt CVT) was found to differ from the conventional gearbox belt behavior through practical testing. These differences are most seen in cases where the CVT V Belt gearbox is being used, as all of the aforementioned elements have combined to considerably reduce its effectiveness (varying speed ratio, presence of axial force, also changing tension giving towards external load). According to the findings of the experiment, optimal performance was achieved when the speed ratio between the driving and driven reels was 1.

A model of a rubber belt's CVT dynamics was proposed by Julio and Plante (2011) [17], Numerical approaches are used to find solutions to the model that incorporates Newton's equations of motion also a quantization belt. Each individual part takes into account the bending moment's equivalent force, the tension at each node, the radial force, the axial force applied to pulley, the belt's friction, and the radial force. The inertia of the belt is ignored in favor of its mass, which is divided by the model's node count.

Separately, Karam and Play (2013) [18], described a quasi-static equilibrium study applied to a metal V-belt drive conducted using a discrete model. Srivastava and Haque presented a comprehensive analysis of the dynamic modeling of belt also chain IVTs, as well as IVT control.

Tsuchiya and Shamoto (2017) [19] Rotational speed in addition to torque can be adjusted by changing engagement time of small slipper clutches in the proposed pulse drive IVT. Duty control, which is employed in electronic voltage converters instead of the more conventional ratio of coil turns, is conceptually similar to this idea.

In Kembraum et al.'s (2017) [20] proposal, the IVT-OP is envisioned in a nested pulley structure. IVT is based on a planetary gear with planets modified to be cones at an angle. The rollers that make up the ring are able to move in tandem with the cones to provide for a wide range of adjustments in contact point radius and, by extension, gear ratio.

Naclerio et al. (2019) [21] Additionally, utilized a 3D printer to create a CVSWT (continuously variable strain wave transmission). A magnetic strain wave gear, compressed metal rollers, a planetary gearing drive using small conical rollers, an orbiting pulley system, in addition a variable gearbox utilizing nested pulleys would all make up this fictitious mechanism. They suggested using the CVSWT when positional precision and stiffness are less important than cost and weight.

Laxman and Scholar (2019) [22] related and contrasted two models: (components of a conventional revolving shift gearbox) and (continuously variable gearbox). The two car models are recommended for use. The (Creo 2.0) program was used for component drawing and static analysis, and the (ANSYS 14.5) program was used to model dynamic stresses. Multiple materials (Steel, E Glass Epoxy, also Carbon Fiber) were chosen in simulations.

The following was the researcher's conclusion:

1. Utilizing CVT is less prone to deformations, stresses, and strains than using a conventional gearbox.
2. Steel is heavier than additional materials suggested for use in the investigation (Carbon Fiber and E Glass Epoxy) while having lower stresses. Shear strain during a random vibration test is reduced when carbon fiber is used as opposed to (Steel), and is also reduced when using (E Glass Epoxy).

3. CVT is preferable because it has fewer mechanically complex components.

4. Composite materials (Carbon Fiber & E Glass Epoxy) are preferred since they are lightweight and allow for mechanical property control.

Using MATLAB, Culebro and Villar (2019) [23] created a numerical model to compute and analyze torque also angular velocity, and they also developed a test model to evaluate the accuracy of their calculations. There are two pieces to the device that must be put together during setup. The first section is like a continuously variable gearbox (IVT) — V-Belt; however, with this device, you can acquire reverse and neutral gears without a clutch, reducing the device's size and weight. This power vector is designated as (IVT) because it is the result of an infinitely variable rate of control. Given these characteristics, it is possible to implement (IVT) in wind turbines and automobiles. Results from actual operations have been displayed and compared to those obtained theoretically. Very near matching, in addition to the test model's device working silently and effectively.

Ajay (2021) [24] published a study on conventional automatic and manual gearboxes with many fixed gear ratios that keep the engine working within its optimum performance band. The importance of gearbox systems and the philosophy behind how a IVT works are extensively covered. A study was conducted to evaluate the contribution of the IVT transmission's hydraulic motor. In Ajay study, he suggest a flexible, compliant, and modular communicative robot. To learn more about the continuous robot, kinematic studies and joint dynamic simulations are carried out. This research proposes a continuous robotic solution for non-structural inspection tasks, which may find use in the field despite the challenges posed by the environment.

Harvester motor load regulation is problematic due to fluctuating field conditions, a broad diversity of machine types, and a sensing lag, according to Peschke et al. (2021) [25]. A controller that employs geospatial data gathered before crop sensing to respond to changing field conditions is presented in this research. A model predictive control technique is used to calculate velocity planning for the next sampling round and incorporate biomass forecasts. Velocity mapping converts geographical data into the time domain for the control algorithm. Different machine setups and nonlinearities are considered by modelling the combined harvester's dynamic behavior and power distribution offline and adjusting online. Simulation and field test results demonstrate the benefit of proactive knowledge.

2.3 Non-Traction IVT systems

Benitez et al, (2004) [26] examined, experimentally, mathematically, also analytically, a device that fits category of ratcheting and includes a gear group (IVT). Following a description of the device's parts' movement mechanism, the program created numerical simulations for dynamic analysis (ADAMS). The study came to the conclusion that the oscillation speed that resulted from the application of (ratcheting). The researcher proposed one of two solutions to solve this issue: first is to use a flywheel that joins at exit axis. The power transmission frequency is brought into alignment with the ICE frequency using the second method. IVT can be applied in motor vehicles using these two techniques.

For a cam-based system, Abood (2010) [27] proposed a theoretical idea with a simulation model (IVT). To achieve a smooth change in the output, the system had two components. The mathematical model that was utilized to explain the theoretical part included the relationships between displacement, velocity, and acceleration.

System outputs were shown to be constant in response to inputs of the same stability. With more than two units, speed ratio changes between inputs and outputs will be less likely to cause oscillations.

In their research, Morales and Benitez (2014)[28] put out a number of correcting designs. Numerical and analytical analyses were conducted to identify the most suitable design. A ratchet clutch-based IVT system was introduced as an alternative to conventional traction IVT. This system's several replicas are all designed around a cam and follower mechanism in three dimensions. One-way clutches, or ratchets, are frequently the most fragile parts of ratcheting IVT systems.

Experimental research on the impact of lowering complexity on the enhancement of IVT performance in cars was conducted by Nummelin (2017) [29]. The two models suggested were. The researcher came to the conclusion that the following characteristics effectively distinguished the proposed mechanism in the two fabricated models:

1. Net torque with flat outlet.
2. Suggest straightforward ways to make the previously employed device less difficult.
3. The ability to get speed values (neutral, opposite, forward), as well as infinity.

An innovative cam-based IVT's theoretical analysis was given by Al-Hamood et al. (2018) [30], Adjusting the slotted rod's vertical distance from the grooved wheel changes the speed ratio. A greater ratio results in a greater acceleration and velocity along the exit axis. Researchers found that there was a change in angular velocity and acceleration at the shaft's output due to the system. Even if the oscillation value is small, it nevertheless occurs whenever the speed of slotted rod is

not zero. Therefore, it is recommended to install a flywheel on the outlet shaft. In addition to acquiring the outlet axes, the proposed IVT may also transfer substantial torques. In a one-way clutch, it is acceptable to make use of this feature.

An experimental also analytical model intended for an IVT-type transmission was put forth by Bhusal et al. (2018) [31], the researcher came to the conclusion that the theoretical and practical computations are extremely similar. By lowering the quantity of clutches, the conveyor's weakest component, this increases the conveyor's durability and confidence. The conveyor has a significant amount of torque also power transmission capacity. Torsional shaft type of power transmission shaft is particularly effective. By reducing the stresses and loads on the clutches, this characteristic allows for the transmission of relatively heavy loads.

Olyaei et al. (2019) [32] A novel power and motion vector (IVT) model was presented, and it was determined that, in comparison to the cam-based gearbox, this mechanism consistently delivers speed with minimal stress. This makes it ideal for use in turbines thanks to the high torque and speed it transmits. Furthermore, it is inexpensive to manufacture, maintain, and install.

The angular mechanism's output (displacement, velocity, and acceleration) has been the subject of theoretical investigation by Al-Hamood et al. (2020) [33], who focused on the one-way clutch. to produce the desired output, the clutches cut the positive or negative component, or vice versa. It was determined that clutch slipping is increased when the transmission ratio in a (IVT) is raised. Rotational springs may be employed to provide the additional torque the wheels need to complete the return stroke.

(2015) Shinde and Khan used a practical test device to enhance the IVT devices' design. The allowed cost and the available raw materials were taken into

account when making the alteration. The CATIA V5 program was used to create a 3D model, and ANSYS and a stress analysis and kinematics calculation were performed. They came to the conclusion that it was feasible to achieve infinite speed without the use of a clutch (low cost, size, also overall weight), and that test device's mechanical output smoothness was good and closely matched the theoretical results.

2.4 Concluding Remarks:

The mechanism's torque transmission and velocity change rate between the rotational of the inputs axes and the exit have been the focus of previous years of study in the field of dynamic mechanics. In recent years, the companies have demonstrated the significance of applications that call for speed and torque adjustments on the fly. The researchers employed experimental, theoretical, or a combination of both research methods in their study for (CVT-IVT). One of the most intriguing forms of power transmission technology is the IVT, particularly when it comes to variable capacitance. The majority of researchers compared the experimental findings with the theory to determine the likelihood of IVT. However, despite numerous prior studies of IVT systems, they still require further research and development to increase efficiency. These investigations will clarify the CVT- IVT principle of action in more detail. The present study calculates the kinematic analysis at several points to produce varied speed ratios at the exit, given that the angular velocity of the entering shaft is fixed. Because of the foregoing, and in order to determine the device's stability under stress, a three-dimensional model was developed.

CHAPTER THREE: THEORETICAL AND SIMULATION ANALYSIS

3.1 Introduction

The theoretical components of the IVT system under discussion are presented in this chapter. It provides examples of the derivations and presumptions that were employed in the analysis and research of the (IVT) system. The governing equation of motion, or formula, is solved using a variety of techniques. Then, kinematic analysis equations were used to assess the output axle's rotational speed and acceleration. The creation of several cam profile types is covered in this chapter as well. [36]

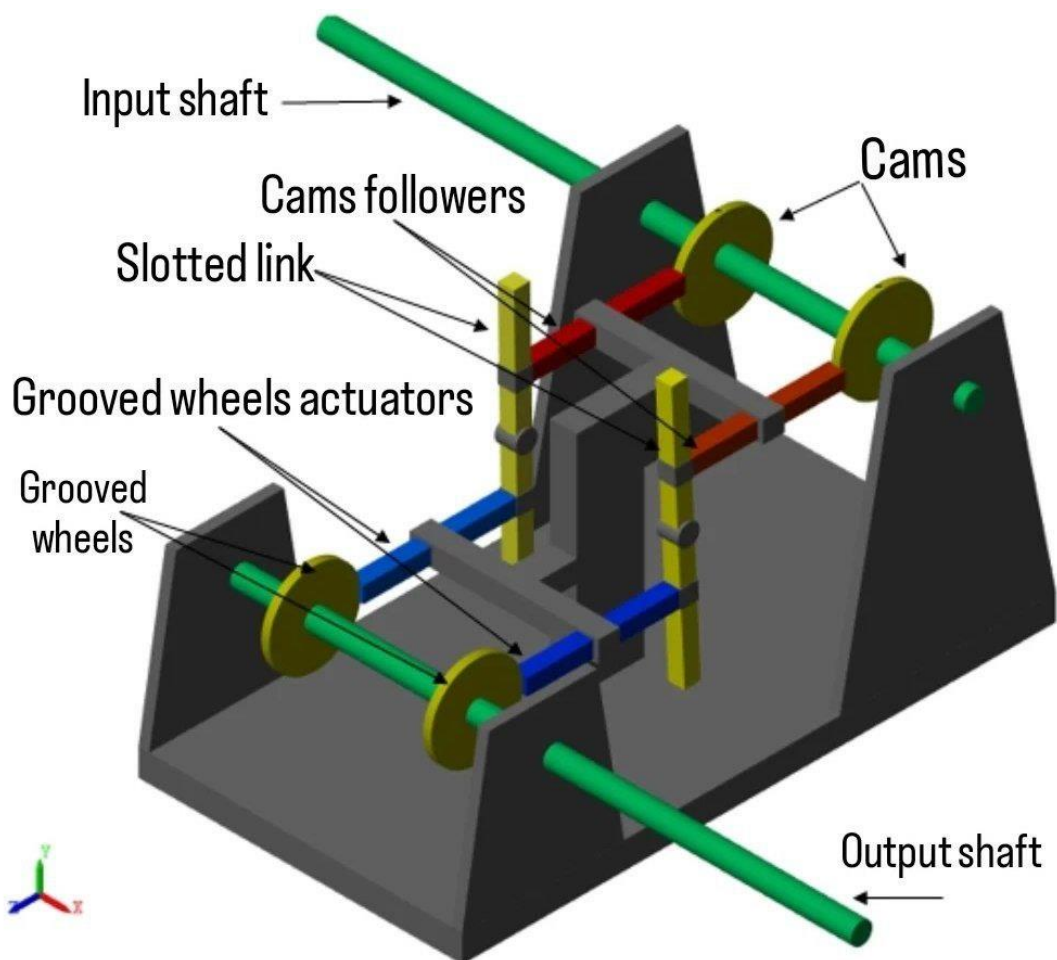


Figure (3-1) Current infinitely variable transmission system

3.2 Cam profile

Two types of cam profiles will be discussed in this chapter:

3.2.1 Constant-constant profile

In this section, for a single unit, the kinematic of the proposed system for the constant-constant Cam profile is established. The system's kinematics are depicted schematically in Figure (3-2).

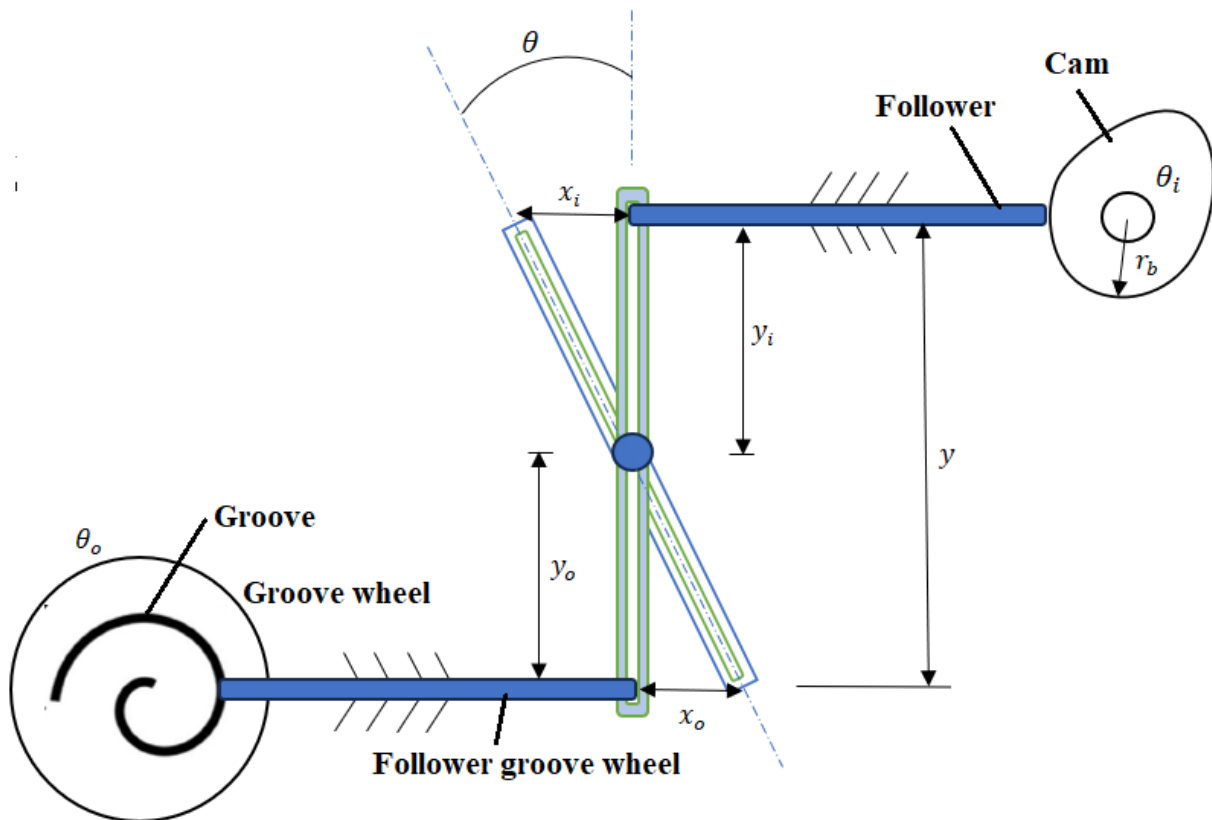


Figure (3-2) Operating of a single unit of constant-constant cam profile

The follower's displacement equation during Cam rotation may be expressed as:

$$x_i = r_b + c_i \theta_i \quad , \quad (\pi \leq \theta_i \leq 2\pi) \quad (3-1)$$

Where:

r_b : Cam radius of base circle = 24.29 mm

c_i : constant of proportionality = $(62.63 * \frac{\pi}{2})$

θ_i : Cam angular displacement of input shaft

The equation below is a differentiation of equation (3.1) with respect to time

$$\frac{dx_i}{dt} = c_i \frac{d\theta_i}{dt}$$

Or

$$\dot{x}_i = v_i = c_i \omega_i \quad (3-2)$$

Where:

v_i : Cam follower velocity

ω_i : Cam angular velocity

Once more differentiating equation (3-2) with regard to time yields the acceleration:

$$\ddot{x}_i = a_i = c_i \frac{d\omega_i}{dt} = 0 \quad (3-3)$$

The second unit operates on an active stroke, yet the first one is in the backward stroke, As can be observed, the acceleration moves in the direction of $(\infty, -\infty)$ during the abrupt shift in velocity when $i=(0 \text{ and } \pi)$. The place where the cam and follower meet requires an unfathomable amount of strength, which might cause component failure. For the return stroke, a polynomial (1–5) cam profile was created., this problem may be solved. The displacement, velocity, and acceleration of the follower exhibit a predictable and gentle actions when the constant velocity

and poly (1–5) curve profiles are coupled. The next sections give a detailed presentation of the equation explaining the profiles at all intervals.

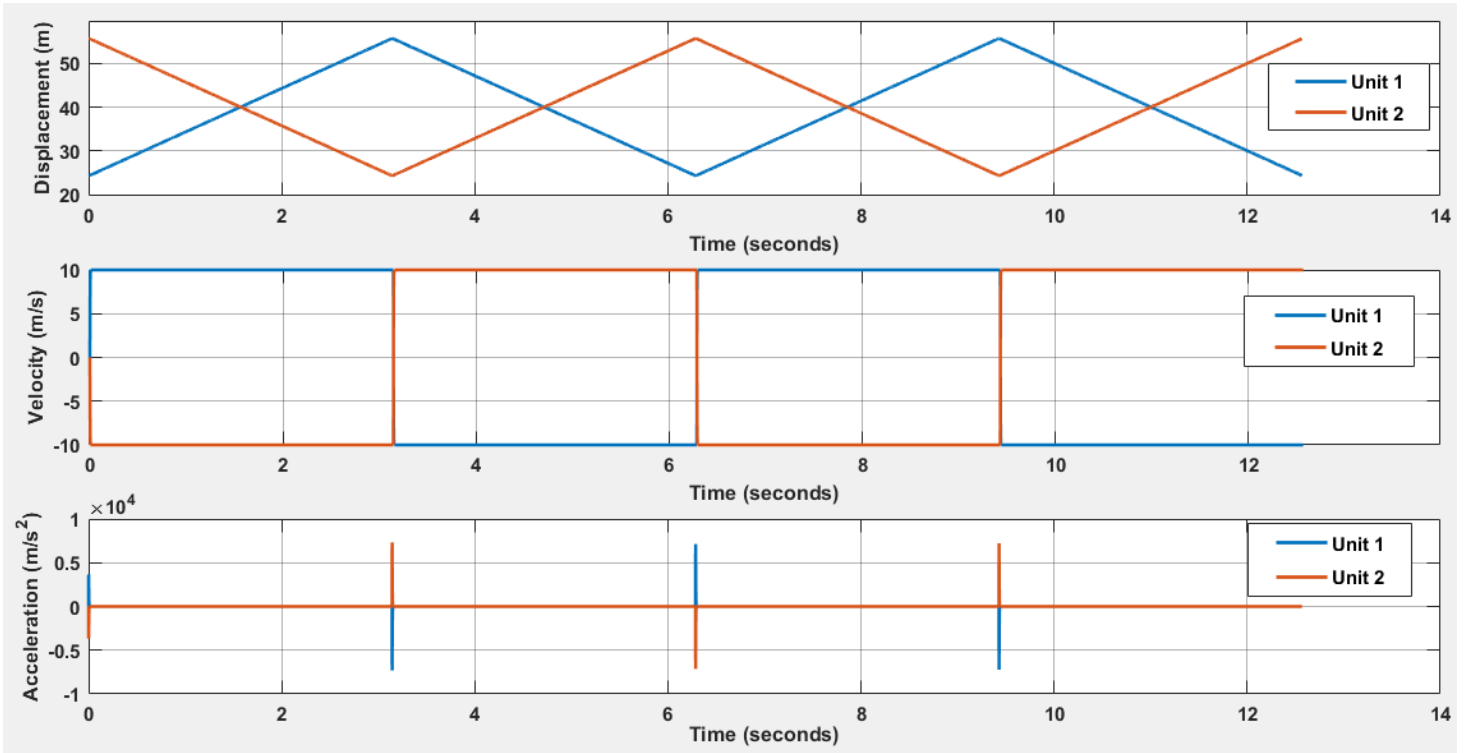


Figure (3-3) Displacement, velocity and acceleration for Constant Velocity profile

3.2.2 Constant-polynomial (1-5) profile

A profile of fifth-degree polynomial is recommended for the returning stroke in order to deal with the issues of prementioned profile.

The general equation of the chosen profile

$$x_i = a_0 + a_1\theta_i + a_2\theta_i^2 + a_3\theta_i^3 + a_4\theta_i^4 + a_5\theta_i^5 \quad (3-4)$$

Where:

a_0 - a_5 : Constants

x_i : The displacements of the follower

θ_i : The angular displacement

A time respect differentiation of equation (3-4), the velocity and acceleration relations are shown. This results in:

$$v_i = a_1 \dot{\theta}_i + 2a_2 \theta_i \dot{\theta}_i + 3a_3 \theta_i^2 \dot{\theta}_i + 4a_4 \theta_i^3 \dot{\theta}_i + 5a_5 \theta_i^4 \dot{\theta}_i \quad (3-5)$$

$$a_i = 2a_2 \dot{\theta}_i^2 + 6a_3 \theta_i \dot{\theta}_i^2 + 12a_4 \theta_i^2 \dot{\theta}_i^2 + 20a_5 \theta_i^3 \dot{\theta}_i^2 \quad (3-6)$$

3.3 Alterable slotted link

The kinematics of the slotted link should be established using the geometric relationship shown in figure (3-2). The angular displacement of the slotted link is represented, as may be seen in the following equation.

$$\frac{x_i}{y_i} = \frac{x_o}{y_o} \rightarrow x_o = \frac{x_i y_o}{y_i}$$

$$\tan \theta = \frac{x_i}{y_i}$$

$$\theta = \tan^{-1} \frac{x_i}{y_i} \quad (3-7)$$

Where:

θ : Alterable slotted link angular displacement.

x_i : Cam follower liner displacement.

y_i : Alterable slotted link axis of rotation to the line of motion of the cam follower vertical displacement

Equation (3-7) is differentiated with respect to time to get the angular velocity of the slotted link, and the resulting results are as follows:

$$\dot{\theta} = \frac{\dot{x}_i y_i - \dot{y}_i x_i}{(x_i^2 + y_i^2)} \quad (3-8)$$

Where:

$\dot{\theta}$: Angular velocity for alterable slotted link

Equation (3-8) is differentiated with respect to time to determine the angular acceleration of the slotted link, which results in:

$$\ddot{\theta} = \frac{(y_i^2 + x_i^2)[(\dot{x}_i \dot{y}_i + y_i \ddot{x}_i) - (\dot{y}_i \dot{x}_i + x_i \ddot{y}_i)] - [(y_i \dot{x}_i - x_i \dot{y}_i)(2y_i \dot{y}_i + 2x_i \dot{x}_i)]}{(y_i^2 + x_i^2)^2} \quad (3-9)$$

Where:

$\ddot{\theta}$: Alterable slotted link angular acceleration

\dot{x}_i : cam follower linear velocity

3.4 Grooved Wheel followers

The component that is examined in this Section is the follower grooved wheel.

The displacement relationship shown in figure (3-2) may be expressed as follows:

$$x_o = \frac{y_o x_i}{y_i}$$

$$x_o = \frac{y_o x_i}{y - y_o} \quad (3-10)$$

Where:

x_o : Grooved wheel actuator linear displacement

y_o : Alterable slotted link axis of rotation to the line of motion of the Grooved wheel actuator vertical displacement

The velocity of the grooved wheel actuator may now be determined by differentiating equation (3.10) with respect to time.

$$\dot{x}_o = \frac{y_o \dot{x}_i + \dot{y}_o x_i}{(y - y_o)} - \frac{x_i y_o (\dot{y} - \dot{y}_o)}{(y - y_o)^2} \quad (3-11)$$

Where:

\dot{x}_o : Grooved wheel actuator linear velocity

x_i : Cam follower linear displacement

Another differentiation for equation (3-11) will give the acceleration equation:

$$\ddot{x}_o = \frac{(y - y_o)(\ddot{x}_i y_o + 2\dot{x}_i \dot{y}_o + \ddot{y}_o x_i) - (y_o \dot{x}_i + \dot{y}_o x_i)(\dot{y} - \dot{y}_o)}{(y - y_o)^2} - \frac{(y - y_o)^2 (x_i \dot{y}_o + y_o \dot{x}_i (\dot{y} - \dot{y}_o) - x_i y_o (\dot{y} - \dot{y}_o) * 2((y - y_o) \dot{y} - \dot{y}_o))}{(y - y_o)^4} \quad (3-12)$$

Where:

\ddot{x}_o : Linear acceleration of the grooved wheel actuator

3.5 Boundary conditions

The following boundary conditions are taken into account while figuring out a polynomial function's coefficients. The transition between the two profiles for a continuous cam profile should be smooth.

- At $\theta = \pi$

$$x_i = r_b + c_i \pi, v = c_i \omega_i, a = 0$$

Thess values Applied into equations (3-4, 3-5, and 3-6)

$$r_b + c_i \pi = a_0 + a_1 \pi + a_2 \pi^2 + a_3 \pi^3 + a_4 \pi^4 + a_5 \pi^5 \quad (3-13)$$

$$c_i \omega_i = a_1 \omega_i + 2a_2 \omega_i \pi + 3a_3 \omega_i \pi^2 + 4a_4 \omega_i \pi^3 + 5a_5 \omega_i \pi^4 \quad (3-14)$$

$$c_i = a_1 + 2a_2 \pi + 3a_3 \pi^2 + 4a_4 \pi^3 + 5a_5 \pi^4 \quad (3-15)$$

$$0 = 2a_2 \omega_i^2 + 6a_3 \omega_i^2 \pi + 12a_4 \omega_i^2 \pi^2 + 20a_5 \omega_i^2 \pi^3 \quad (3-16)$$

$$0 = 2a_2 + 6a_3\pi + 12a_4\pi^2 + 20a_5\pi^3 \quad (3-17)$$

- At $\theta = 2\pi$

$$x_i = r_b + c_i\theta_i, v = c_i\omega_i, a = 0$$

Thess values Applied into equations (3-4, 3-5, and 3-6):

$$r_b + c_i\pi = a_0 + 2a_1\pi + 4a_2\pi^2 + 8a_3\pi^3 + 16a_4\pi^4 + 32a_5\pi^5 \quad (3-18)$$

$$c_i = a_1 + 4a_2\pi + 12a_3\pi^2 + 32a_4\pi^3 + 80a_5\pi^4 \quad (3-19)$$

$$0 = 2a_2 + 12a_3\pi + 48a_4\pi^2 + 160a_5\pi^3 \quad (3-20)$$

Creating a matrix of the above equations as below

$$\begin{bmatrix} 1 & \pi & \pi^2 & \pi^3 & \pi^4 & \pi^5 \\ 0 & 1 & 2\pi & 3\pi^2 & 4\pi^3 & 5\pi^4 \\ 0 & 0 & 2 & 6\pi & 12\pi^2 & 20\pi^3 \\ 1 & 2\pi & 4\pi^2 & 8\pi^3 & 16\pi^4 & 32\pi^5 \\ 0 & 1 & 4\pi & 12\pi^2 & 32\pi^3 & 80\pi^4 \\ 0 & 0 & 2 & 12\pi & 48\pi^2 & 160\pi^3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} r_b + c_i\pi \\ c_i \\ 0 \\ r_b + 2c_i\pi \\ c_i \\ 0 \end{bmatrix}$$

Solving the above equation and applying the dimensions used in this thesis gives the values of the parameters as can be seen in table 3.1

Table 3-1: Six constants of polynomial equation (*1000)

a_0	a_1	a_2	a_3	a_4	a_5
1.9485	-2.3899	1.1454	-0.2632	0.0290	-0.0012

The combined cam profile based on equation (3-4)

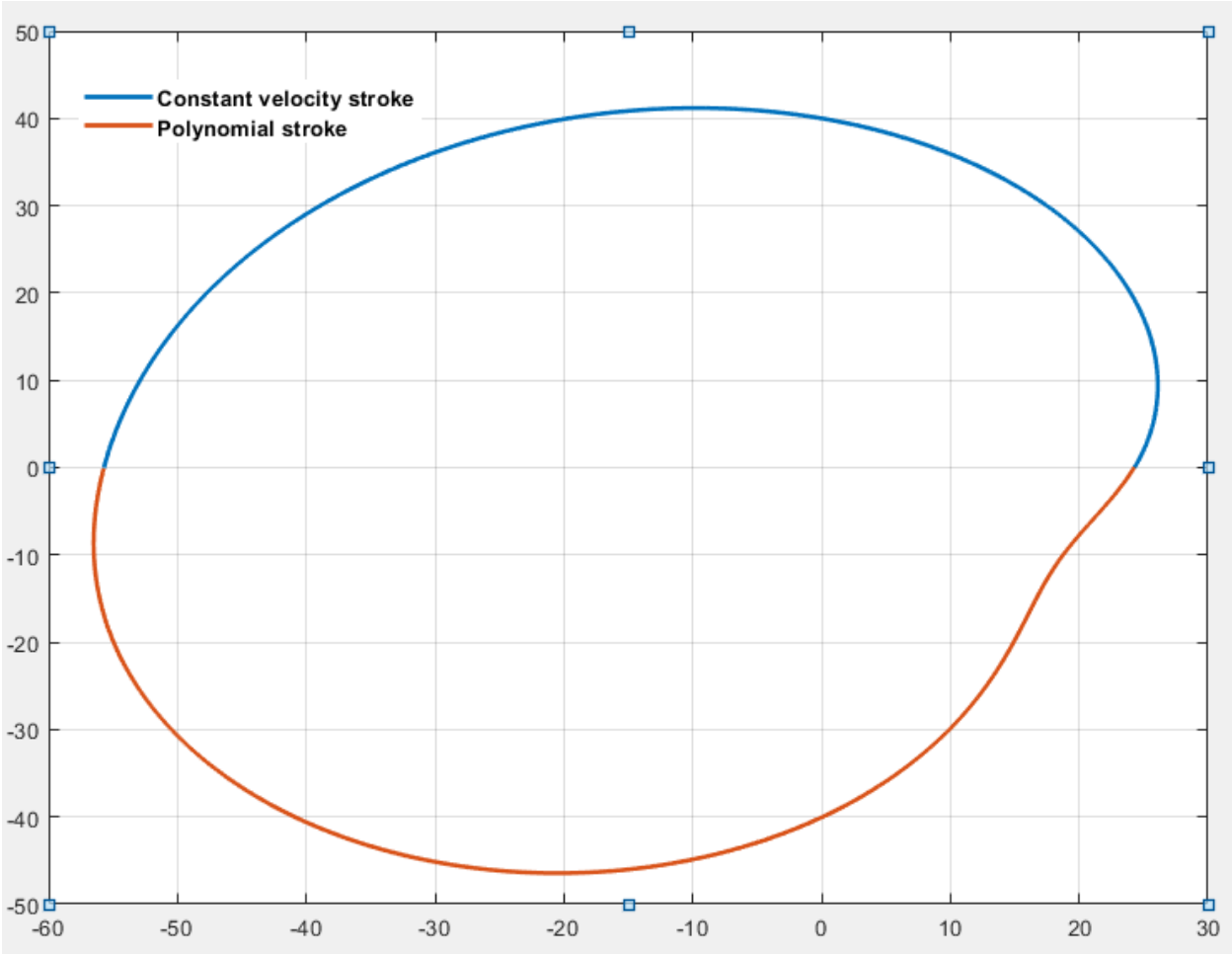


Figure (3-4) Combined cam profile (constant velocity-polynomial)

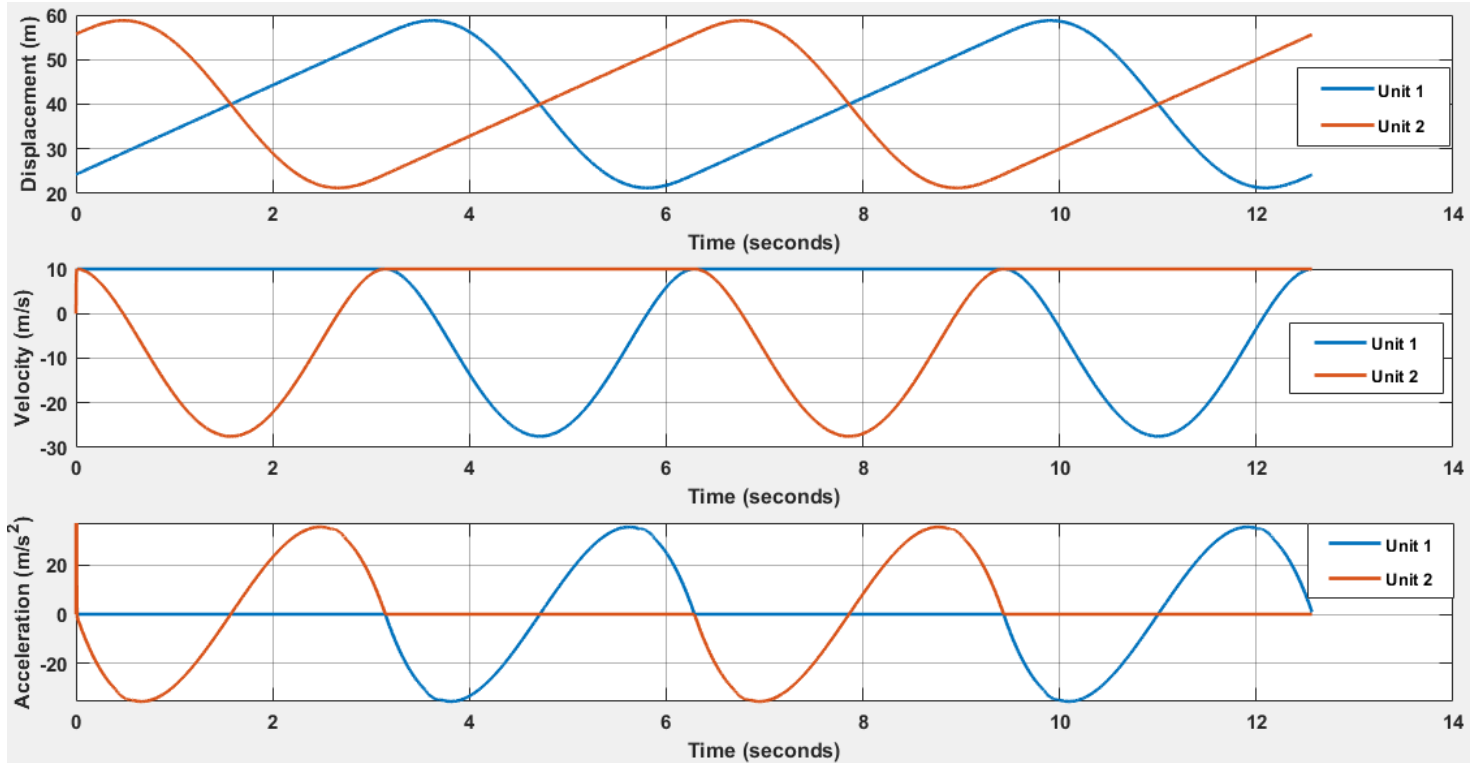


Figure (3-5) Forward and backward strokes displacement, velocity, and acceleration for a cam with a constant velocity-polynomial profile

3.6 Ratchet

The ratchet's purpose is to make the grooved wheel moves in one direction by locking it to the output shaft and unhook it in the opposite direction, as was already described. The return stroke of each unit has a high rubbing (or sliding) angular velocity as a result. This rubbing velocity is determined by the transmission ratio that was chosen for the system. The grooved wheel developed above uses the same kinematic equations that control the motion of the ratchet. The working radius of the ratchet affects the linear sliding velocity. The appendix contains information about the ratchet utilized in this study.

3.7 Simulation part

3.7.1 Introduction

In order to carry out a comprehensive practical study on a mechanical system or mechanism, a fully detailed prototype or model should be manufactured and assembled. Furthermore, this system should be equipped with efficient measurement system to study the different variable during operation. An alternative method to the practical method is the simulation using specialized package software. In this study, MATLAB Simscape is used for this aim, this will be described in detail in the subsequent sections.

3.7.2 MATLAB Simscape

The MathWorks company created the proprietary multi-paradigm programming language and computer environment known as MATLAB (short for "Matrix Laboratory"). Matrix manipulation, function and data visualization, algorithm implementation, user interface building, and connecting with other programming languages are all possible with MATLAB.

Although MATLAB is primarily designed for numeric computation, symbolic computation capabilities are accessible through an optional toolbox that uses the MuPAD symbolic engine. Simulink, a separate program, enhances model-based design and graphical multi-domain simulation for dynamic and embedded systems.

Using Simulink will allow us to simulate our system graphically and get the results we need to determine from the simulation of our mechanism.

Simulink is a graphical programming environment for MATLAB-based multidomain dynamical systems that allows for modeling, simulation, and analysis. Its main user interface consists of a graphical block diagramming tool and a collection of block libraries that may be customized. It may be used to drive

MATLAB or be programmed from it and Simulink offers one brunch that called ‘simscape’ that enables you to quickly build physical system models in the Simulink environment. To create block diagrams and other modeling paradigms that seamlessly interface with actual component models created using Simscape based on physical connections. By integrating basic components into a schematic, we may represent systems like multi-body systems and electric motors

Simscape aids in the development of control systems and the testing of system performance. The MATLAB-based Simscape language allows for text-based writing of physical modeling components, domains, and libraries, allowing us to develop unique component models. Using MATLAB variables and expressions, To parameterize the models, and Simulink can be used to create the control schemes for our physical system. Simscape enables C-code creation for deploying our models to various simulation environments, such as hardware-in-the-loop (HIL) systems.

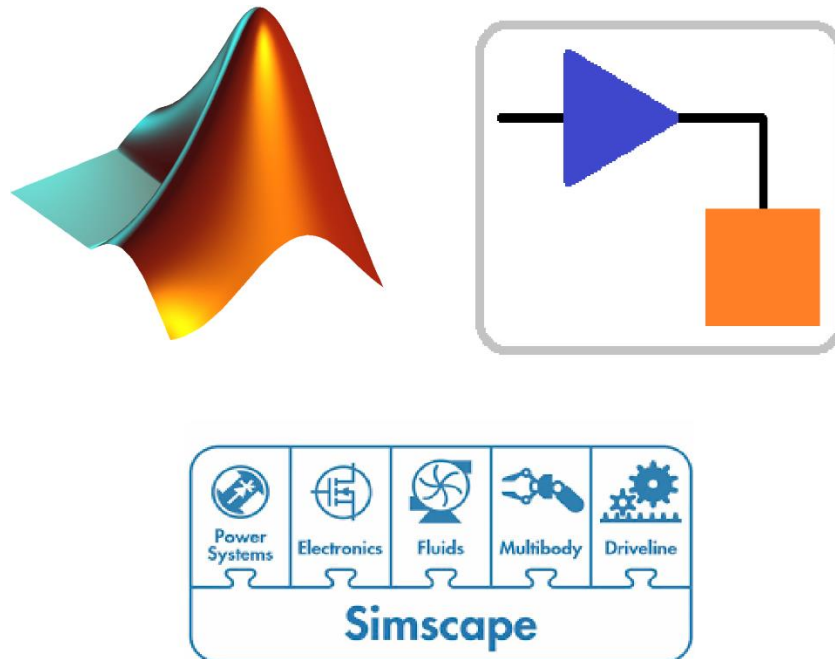


Figure (3-6) Icon of MATLAB, Simulink & Simscape

3.8 (IVT) Simulation Model

The operating principle of the device was modelled by (MATLAB 2022a), as previously mentioned. An original (IVT) three-dimensional model was created. The program library (MATLAB 2022a) was used to select the material parameters for the pieces of the gadget. The cam's shape has been evaluated multiple times.

Simscape is a MATLAB Simulink branch that could be used for simulation of large variety of mechanical systems. In the current work, multibody catigoury is used for the IVT simulation.

In general, simscape is a type of block diagram envaronment connected with each other with links or wires to creates mechanisim or any mechanical systems. Such as cam follower mechanism, springs and dampers system , gear trains and elecitrical components, for example figure (3-7) shows a part of the compepeted block diagram of the mechanism it shows a bodies, joints and rigid transform.

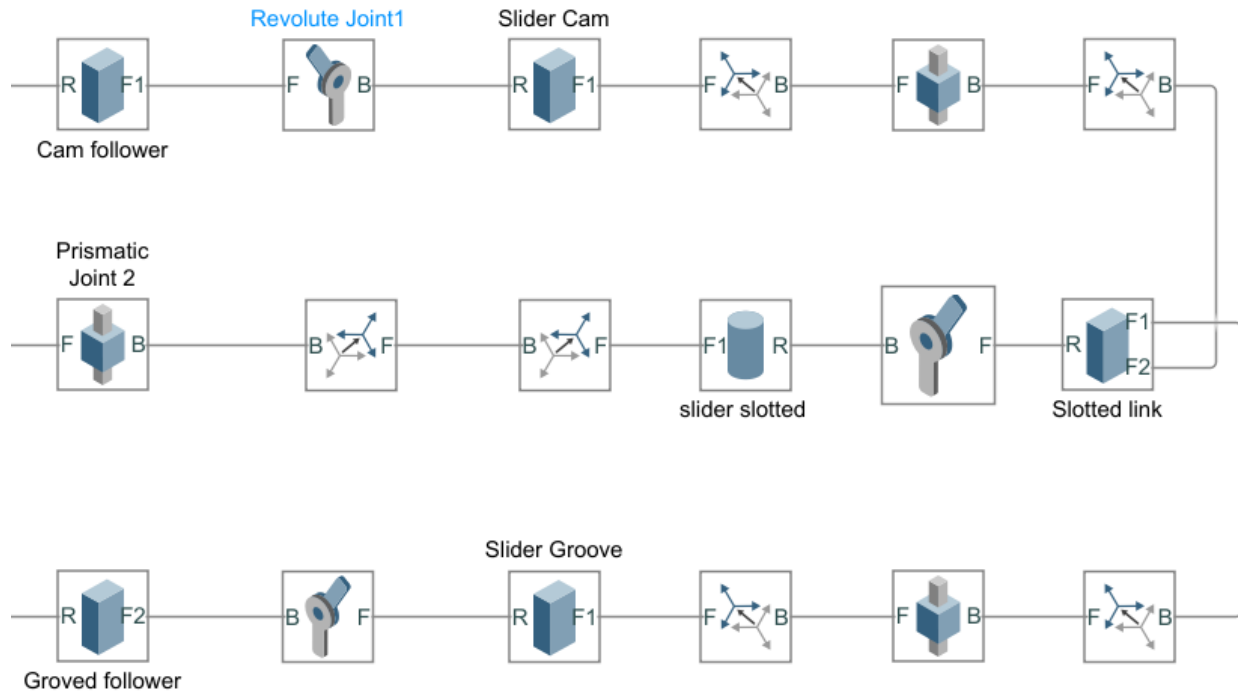


Figure (3-7) Schematic diagram presenting followers and slotted link

Another example of blocks is shown below this is a prismatic joint has two nodes of connections called based and frame also it has an input port and output result which can be read by another block called scope.

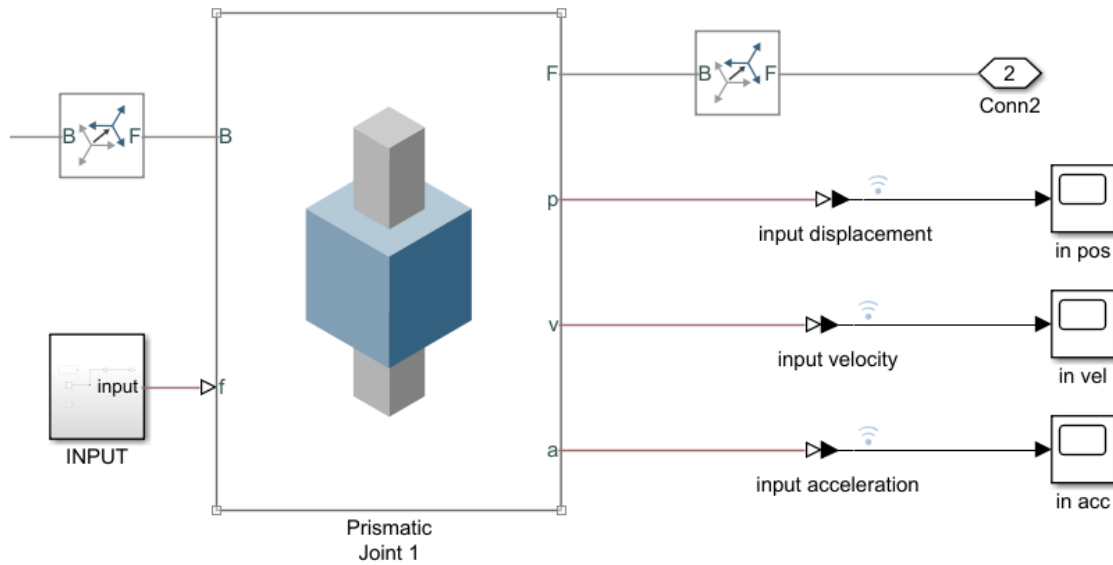


Figure (3-8) Prismatic joint & scope

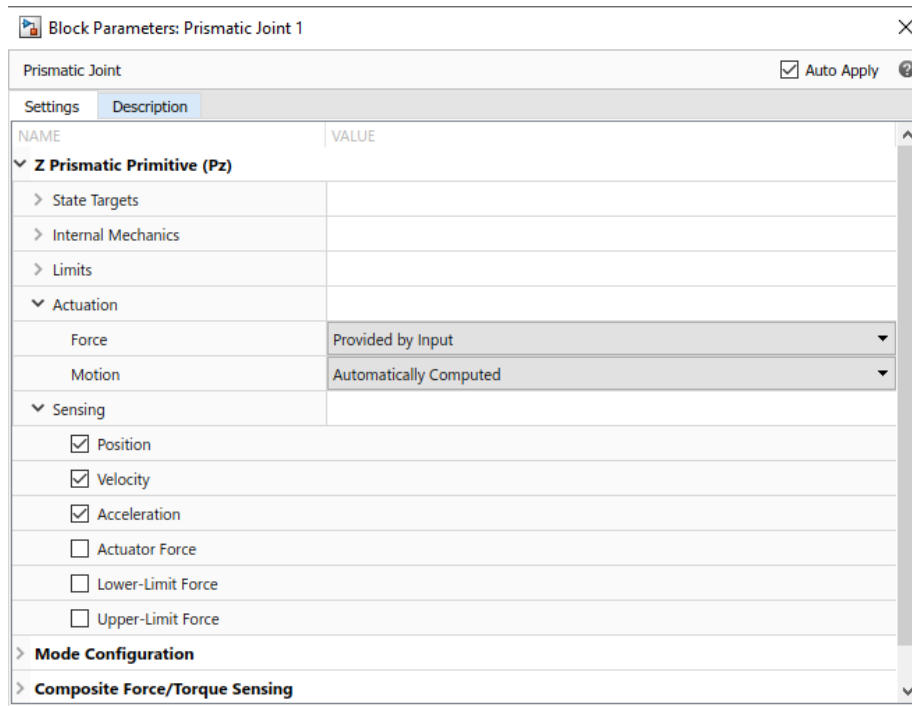


Figure (3-9) Prismatic joint parameter window

3.9 Input and output

Many blocks in Simscape can be used to provide several types of input that can be connected to the joints from actuation port making the mechanism moves as needed such as constant block it provide a constant and continuous value it can be used for shifting parts up or down, or ramp input this type can gives a linear motion increasing or decreasing by constant velocity also there is sine wave input this can be used for constant alternative motion and Signal editor this is the most important because it can provide any kind of input by taking data from MATLAB workspace also it can be interpolate unwanted data all these blocks connected to joints only but it must pass through a Simulink-PS converter first as shown in figure below

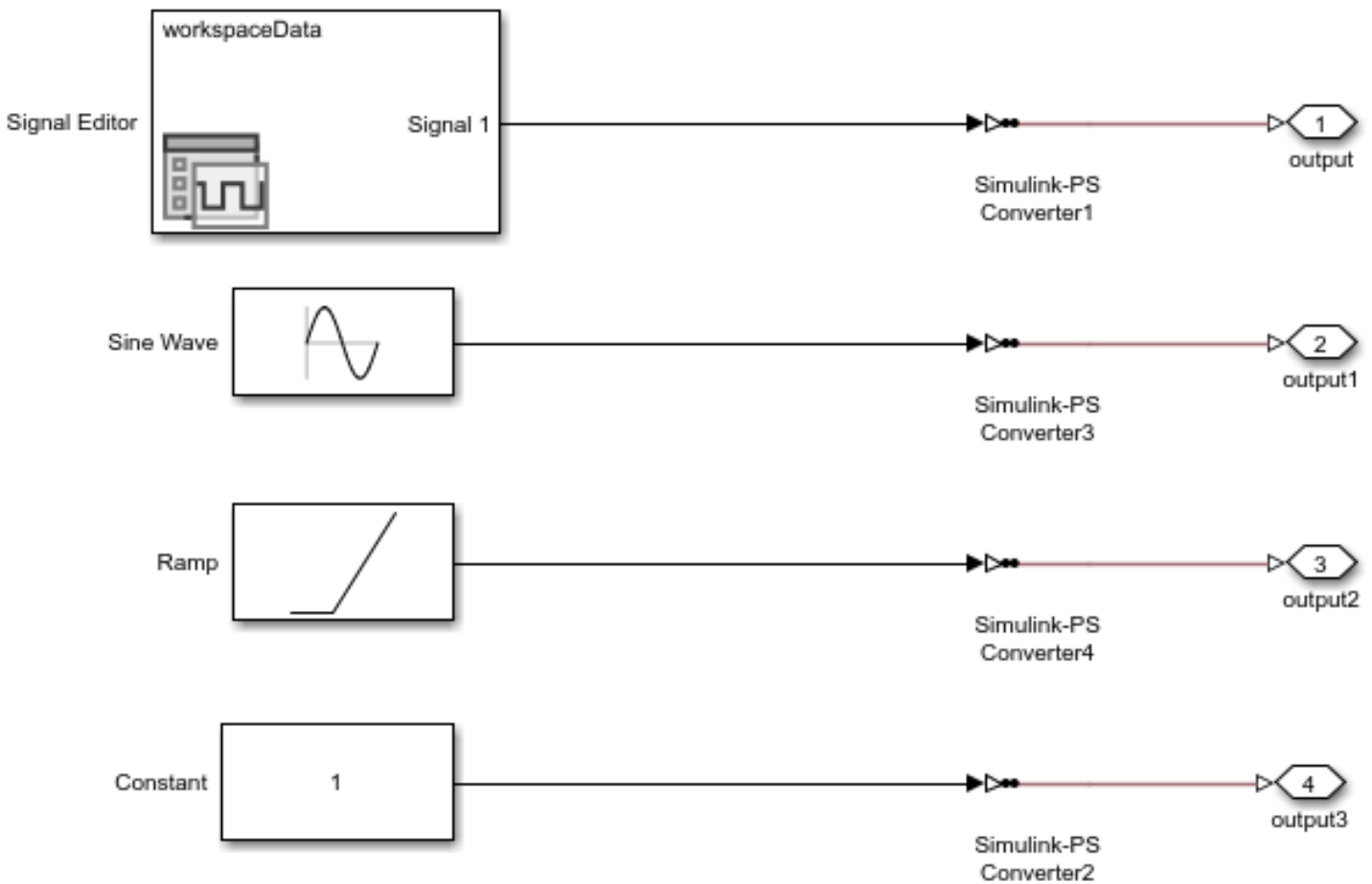


Figure (3-10) Types of inputs

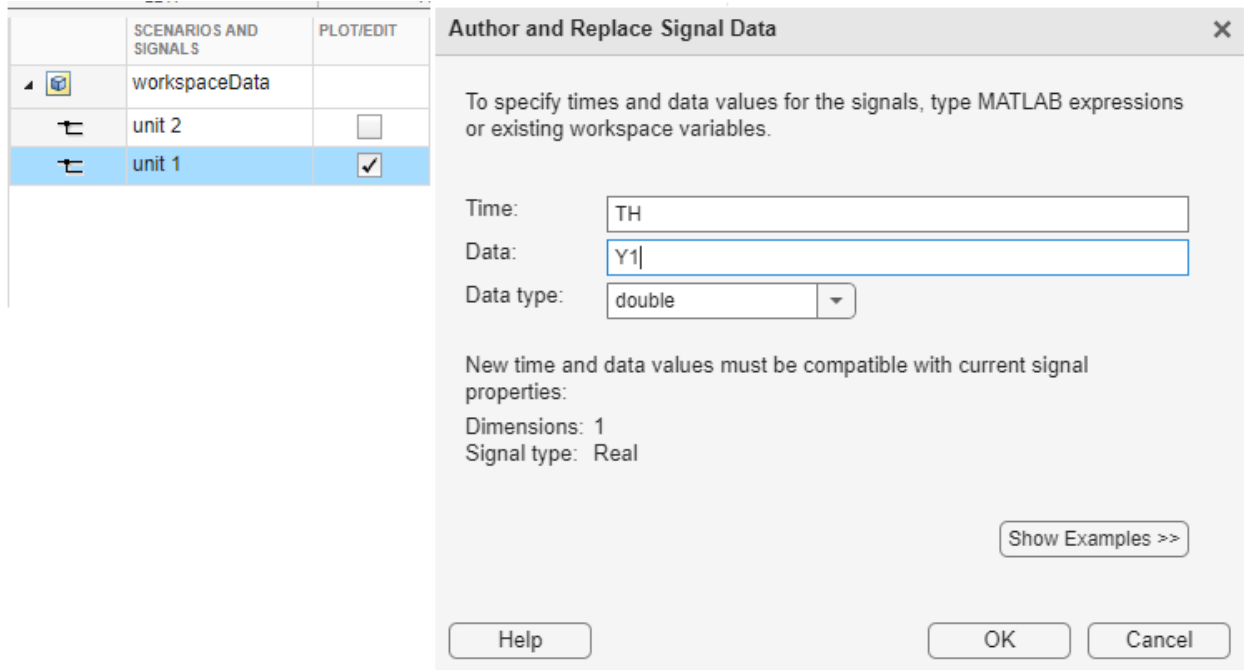


Figure (3-11) Signal editor window

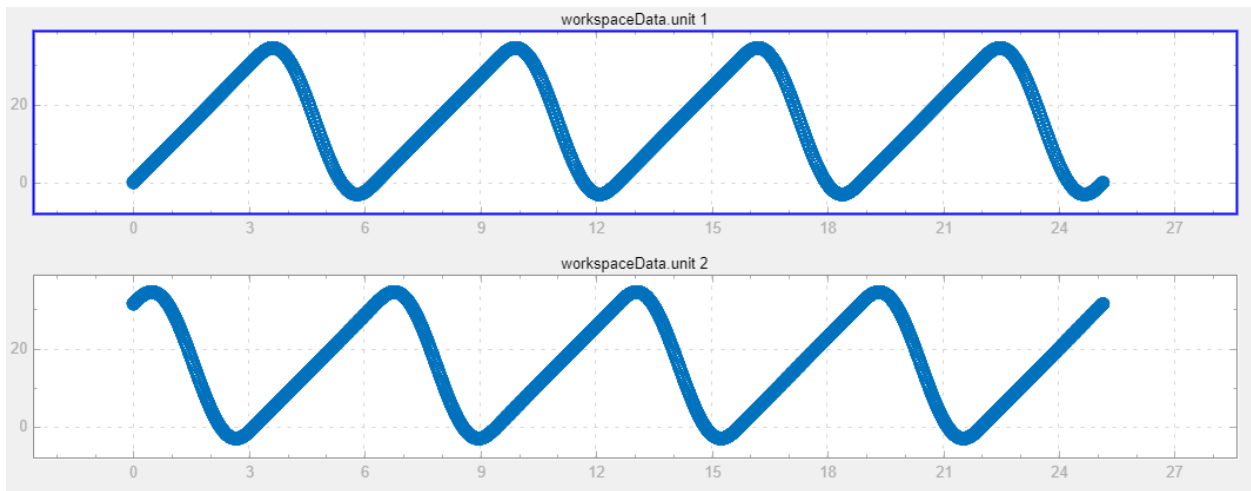


Figure (3-12) Signal editor window (cam followers' motion)

For the output results it can be shown by using a block called scope it connected to the joint also, form sensing port and again it should pass first through PS-Simulink converter or by using data inspector it is a built-in feature of Simscape it can plot several curves in the same time also for each run for compare the results between runs also it can export plots as a MATLAB data file or excel file and many other types. as shown in figure below.

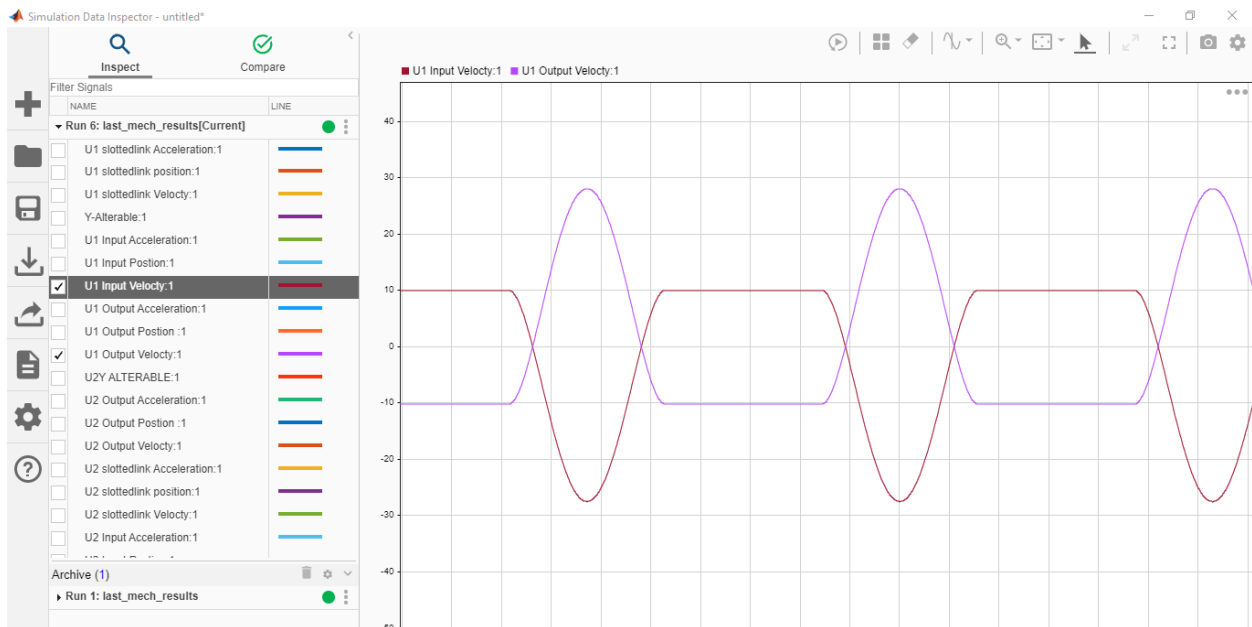


Figure (3-13) Types of outputs

3.10 System parameters

Like any other analysis and simulation software, MATLAB Simulink has its own parameter blocks that solve problems using the equations that are builtin. These parameters, which include the amount and direction of acceleration due to gravity as well as the number of steps required to differentiate an equation and choose the numerical solution as demonstrated, can be changed to suit the particular case being simulated.

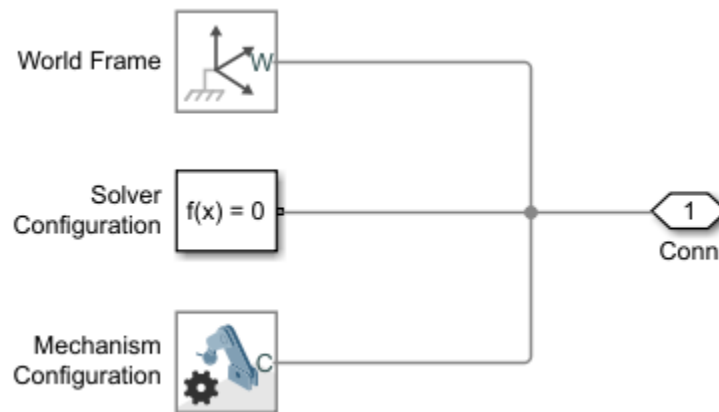


Figure (3-14) System settings

World frame represents the ground and the reference of any calculation done and the solver configuration represents the equation used to solve the problems physically and mechanism configuration used to control the parameter of the problem such as types of derivatives and direction of forces and the step size.

3.11 Mechanism parts and operation

3.11.1 Mechanism parts

The IVT mechanism is presented in a structure of two units joined in a way that can work alternatively (one by one), the parts that construct the IVT mechanism are below:

1. Cam shaft (contains two cams, one for each unit)
2. Cam follower (each cam has one follower)
3. Alterable slotted link (one for each unit)
4. Grooved wheel shaft (contains two wheels, one for each unit)
5. Grooved wheel actuator (each grooved wheel has actuator)
6. Ratchet (each grooved wheel has one ratchet)
7. Main body (for the whole system)

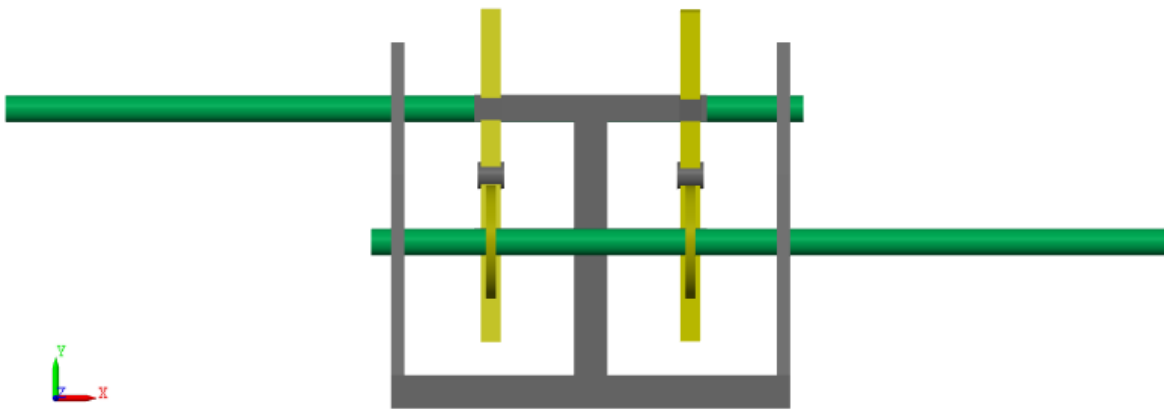


Figure (3-15) Simulated mechanism front view

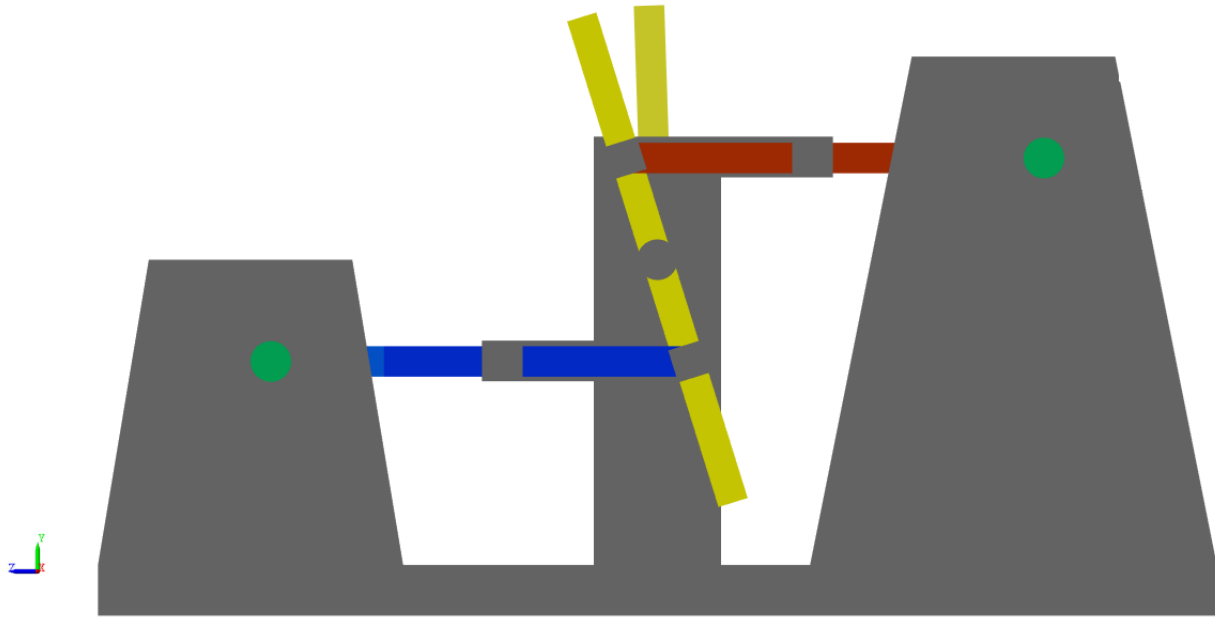


Figure (3-16) Simulated mechanism side view

3.11.1.1 Cam shaft

It's a shaft that contains two cams one cam for each unit as mentioned previously the cam is a two-stroke cam (constant velocity & polynomial), The constant velocity is the active stroke for the mechanism while the polynomial is only the return stroke and each stroke takes a cycle of one pi. By using the following block diagram, the cam shaft is designed

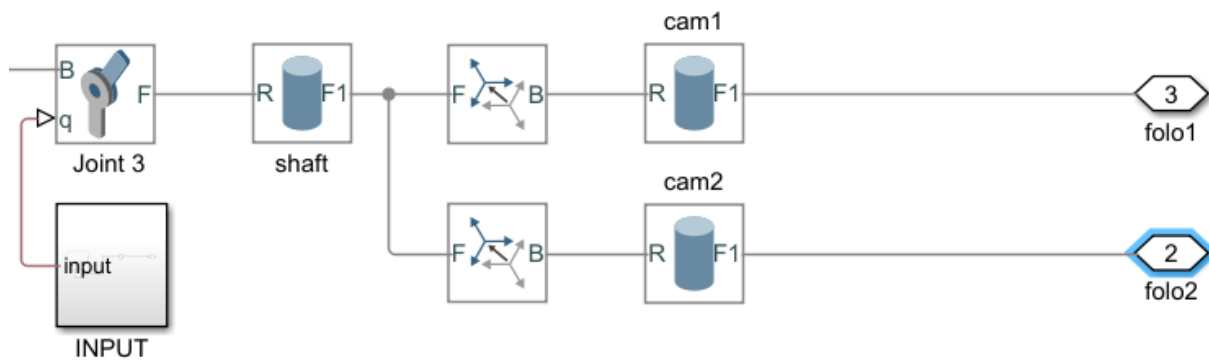
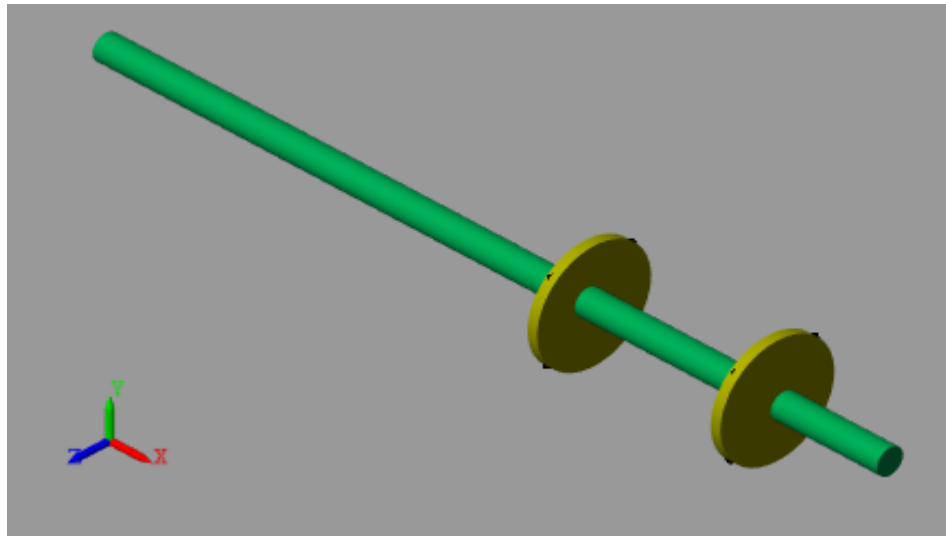


Figure (3-17) Cam shaft

3.11.1.2 Cam follower

The followers have been chosen as a normal rectangle shaped to achieve the performance it's applied for. It's connected and transfer the motion between the cam and the slotted link smoothly block diagram below can be used to construct the geometry of followers.

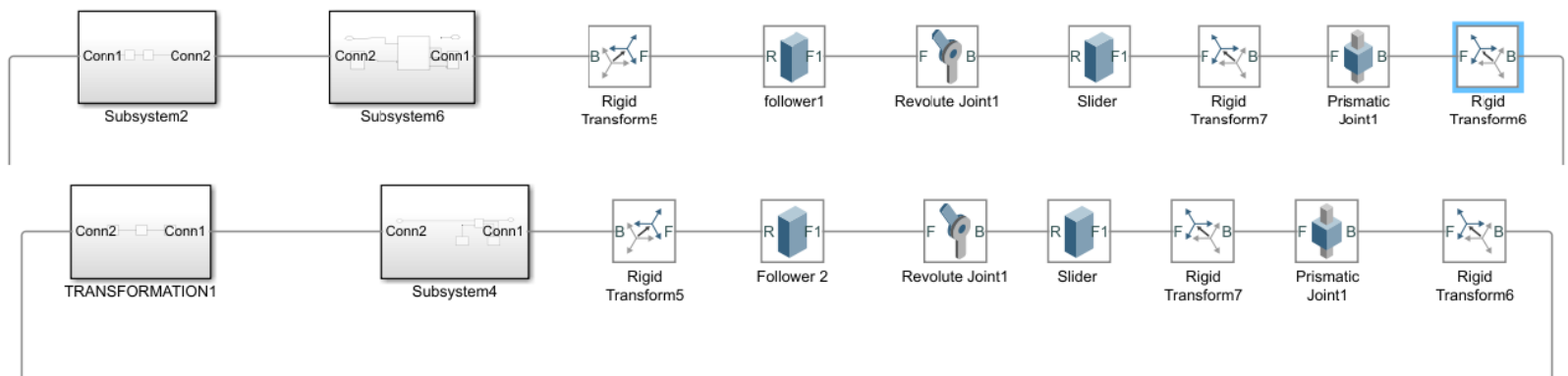
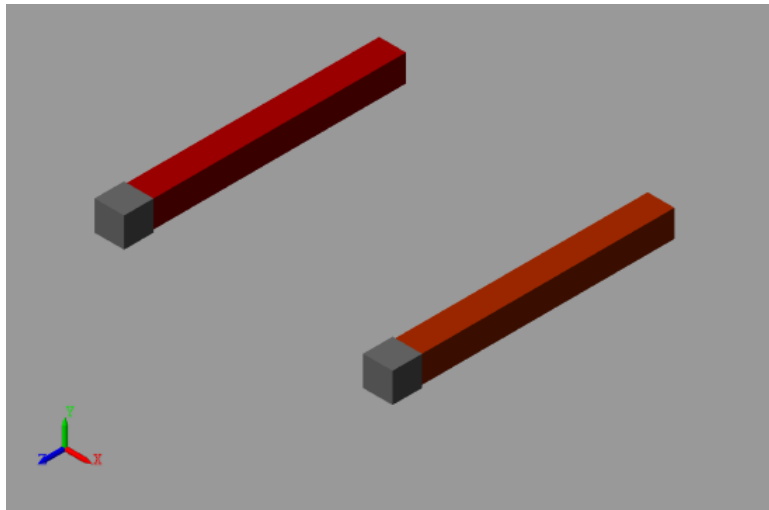


Figure (3-18) Cam followers

3.11.1.3 Alterable slotted link

This is the most important part of the mechanism it represents the heart of the system it connects between the cam follower and grooved wheel actuator in other words it connects between input and output shafts. Slotted link connected in three points of pin-slot joints one from the middle into the main body this joint called alterable joint it can moves upward or downward to control the velocity transmission ratio or fixed at a selected point and also it rotates about its axis. And the two ends connected to the follower and actuator, the upper end for the follower and lower end for the actuator. Its moves alternative motion between the followers by pulling and pushing sequence. The following block diagram represents the slotted link.

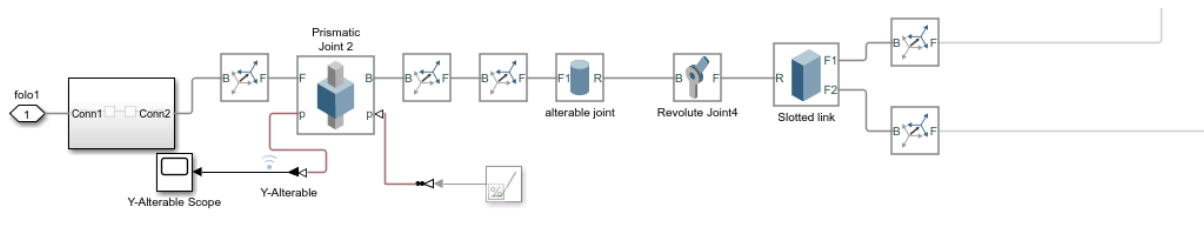
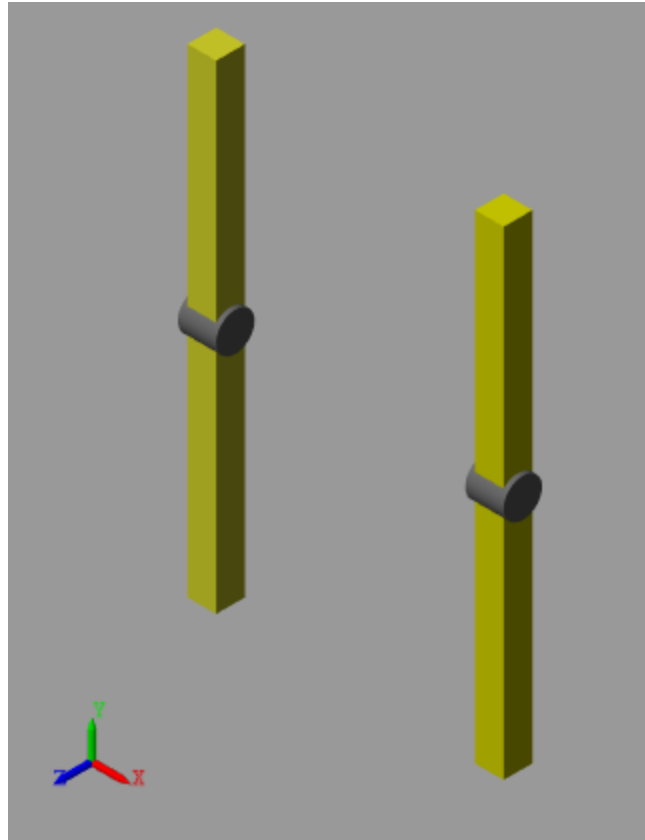


Figure (3-19) Alterable slotted link

3.11.1.4 Grooved wheel actuator

As same as the cam's followers only the type of connection to the grooved wheel is different it has a pin that fits inside the groove of the wheel block diagram below is for constructing the actuators

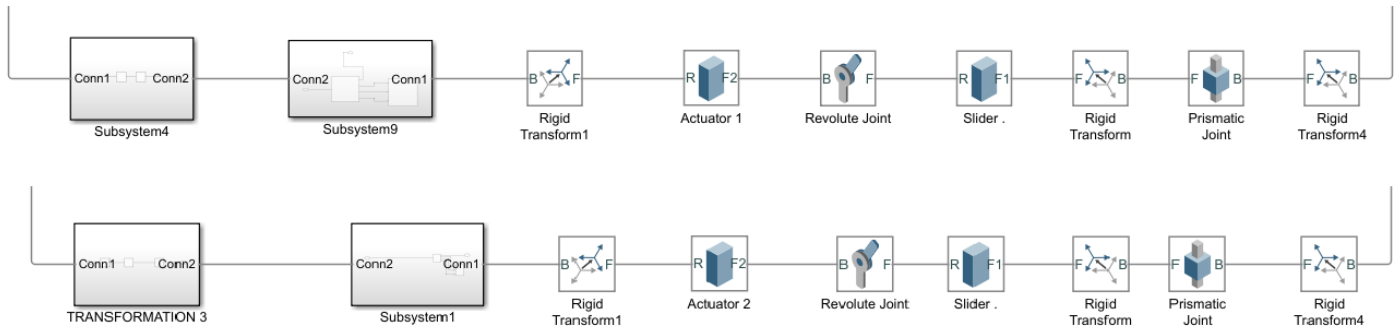
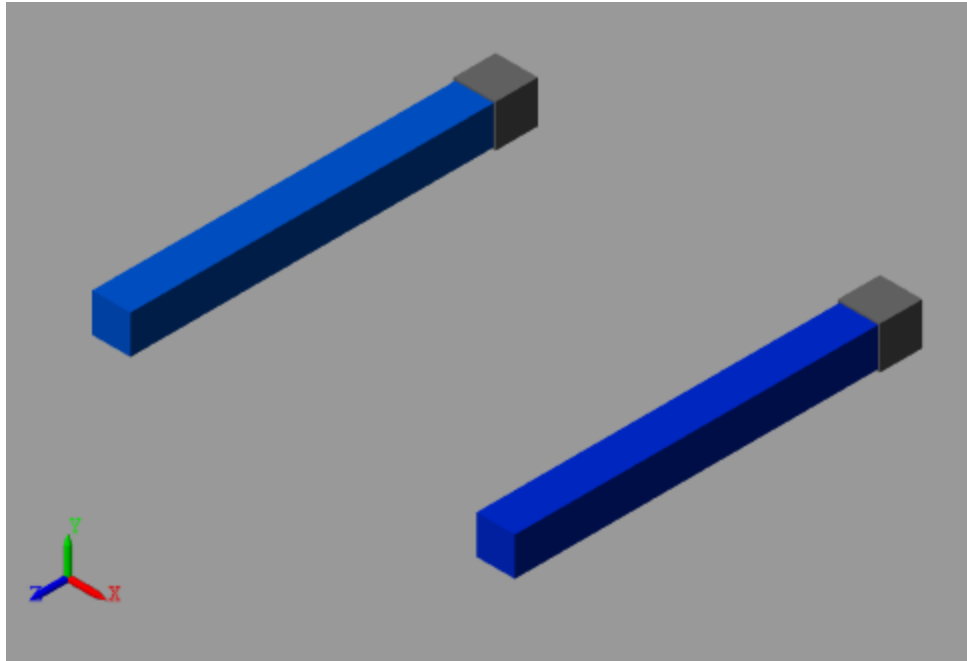


Figure (3-20) Grooved wheel actuator

3.11.1.5 Grooved wheel shaft

It's a shaft contains two grooved wheels that can receive the reciprocating motion comes from the actuator and transfer it to rotating one. The spiral fissure's length of 8 is the cause for this. As the grooved wheel is attached from the side (output shaft) by a mechanism (ratchet), it is constructed as a constant velocity profile. It can be constructed by using the block diagram below.

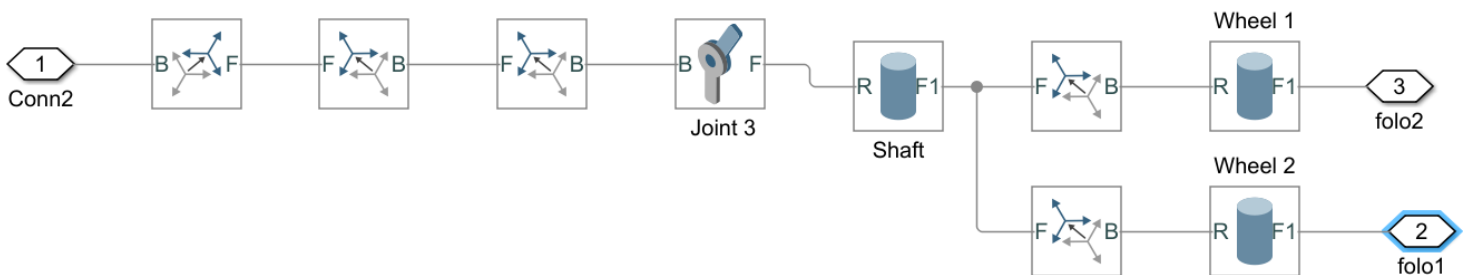
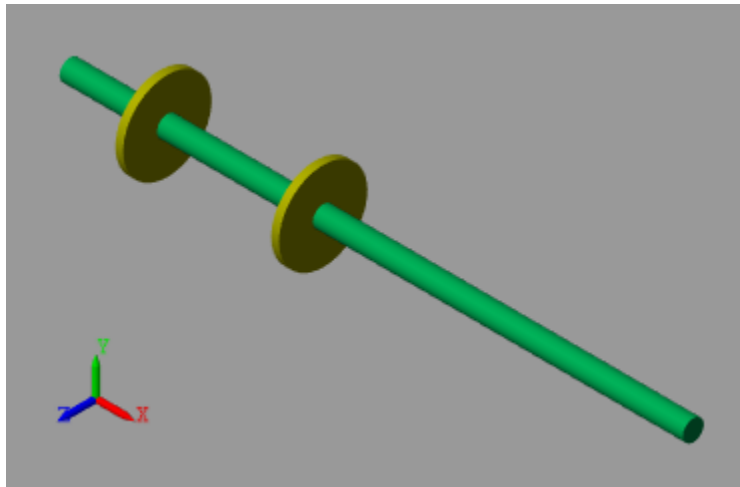


Figure (3-21) Grooved wheel shaft

3.11.1.6 Ratchet

As the rear bicycle derailleur works, this mechanism used to achieve almost the same purpose, it works to convert the reciprocating motion from the grooved wheels into rotational motion in one direction only for the output shaft. It cannot be designed in Simulink so by taking the positive value of the output waves it can archive the same purpose.

3.11.1.7 Main body

The main body or the base of the mechanism is chosen to suit dimension of the mechanism to ensure that all moving particles can move easily without unwanted touching or connection. Each part designed alone then connected by a weld joint and rigid transformation to adjust dimension.

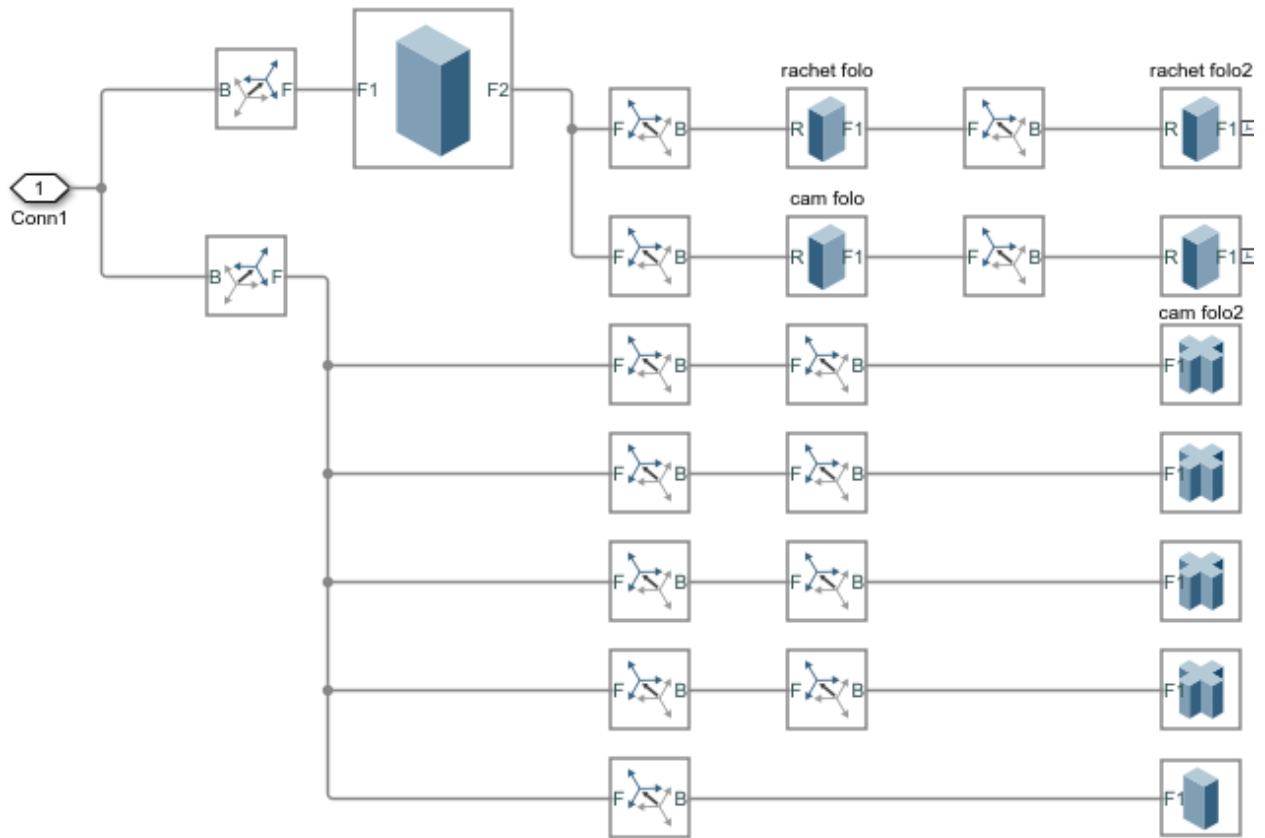
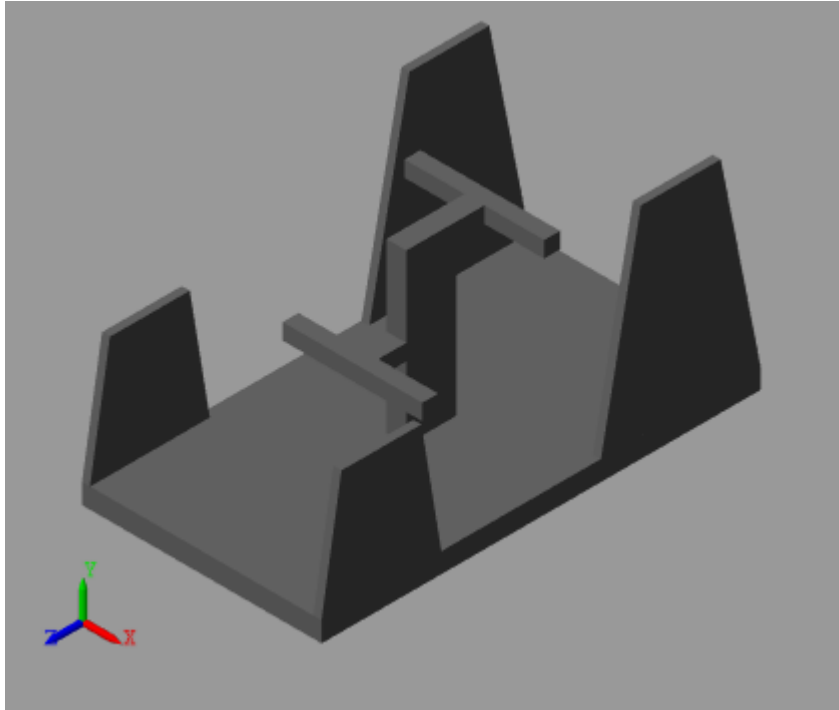


Figure (3-22) Main body

3.12 System Operation

The operation of IVT mechanism can be explained in few steps as below:

1. The input shaft delivers rotating motion, and the motion maintained to be converted to a reciprocating one by the cam-follower mechanism
2. The reciprocating motion becomes the linkage shaft connected in the middle in a way that makes it moves alternatively.
3. The linkage shaft is a slotted link that makes the input and output links slide on its surface to make the movement easier, also this linkage shaft can be moves upward and downward to control the transmission ratio
4. The motion transformed from the linkage link to the output link shaft in a way just like the input shaft is connected and the motion is converted from alternative to reciprocating one.
5. Finally the output shaft connected to ratchet pully to convert the motion again into rotating motion.

3.13 The whole system block diagram

The figures below show the last block diagram constructed by Simulink Simscape it shows a subsystem blocks each one represents a part of the mechanism as showed previously by running this system we gained the results of simulation and this will be showed and discussed in the next chapter.

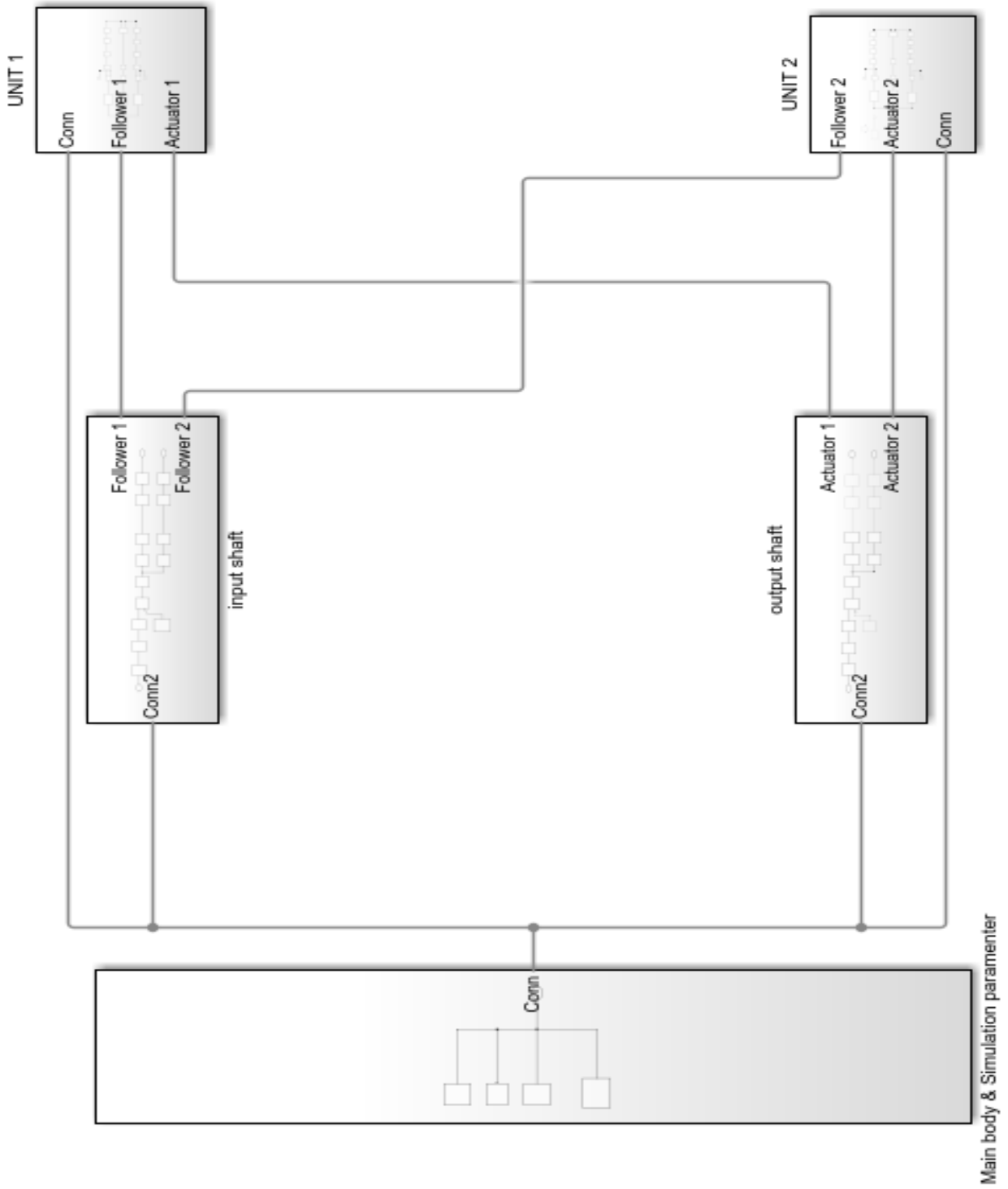


Figure (3-23) Full system simulation

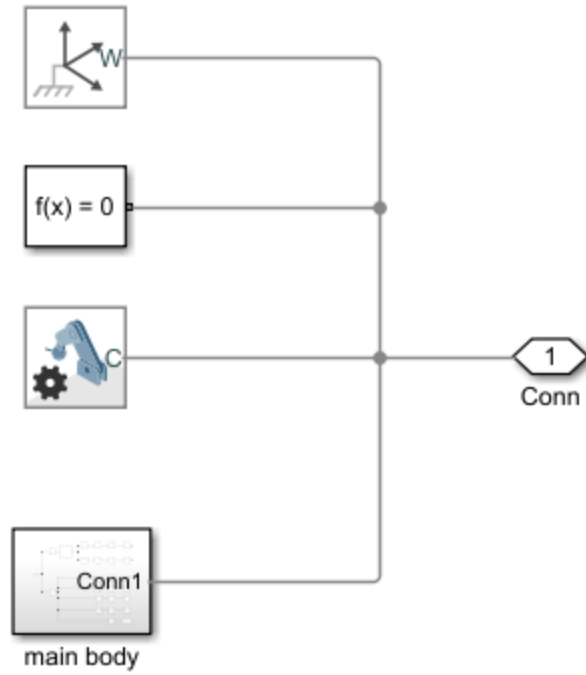


Figure (3-24) Main body & simulation parameter

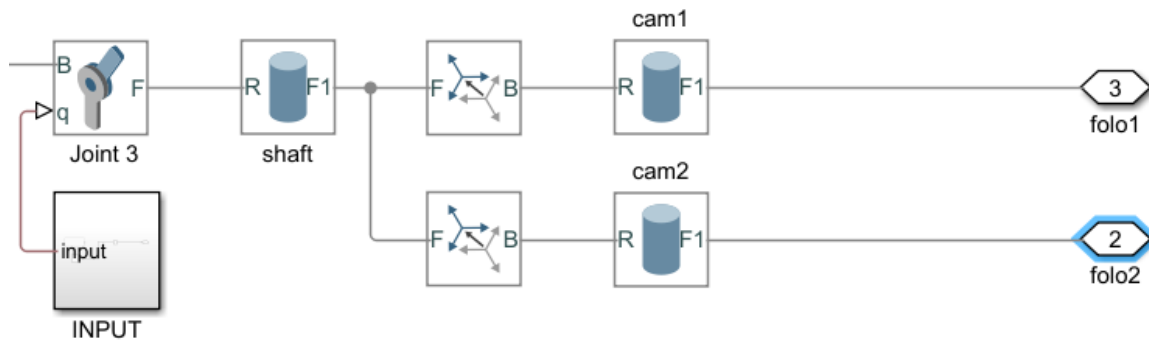


Figure (3-25) Input shaft

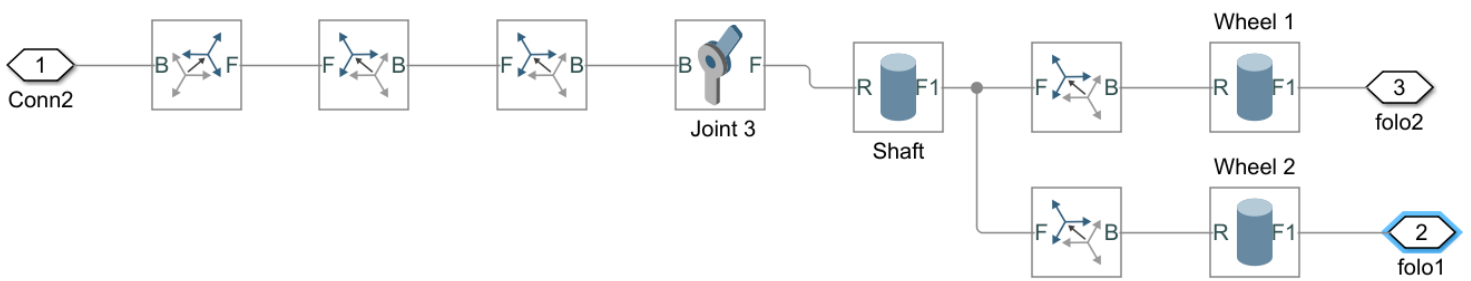


Figure (3-26) Output shaft

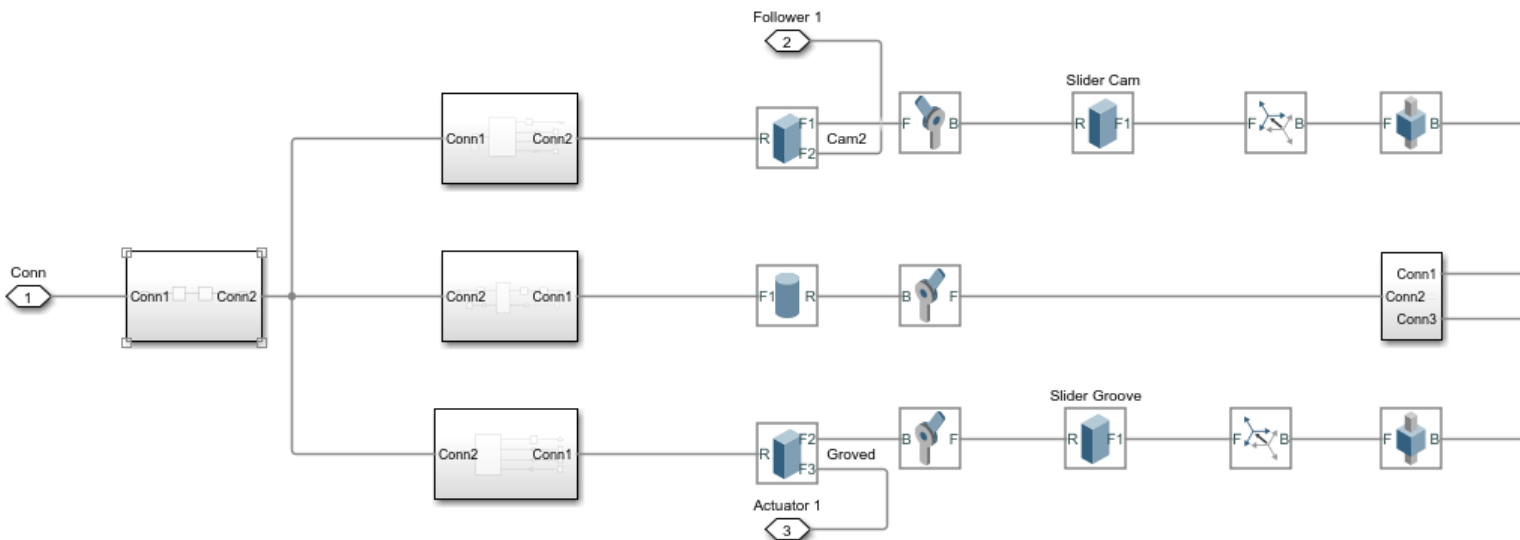


Figure (3-27) Unit one

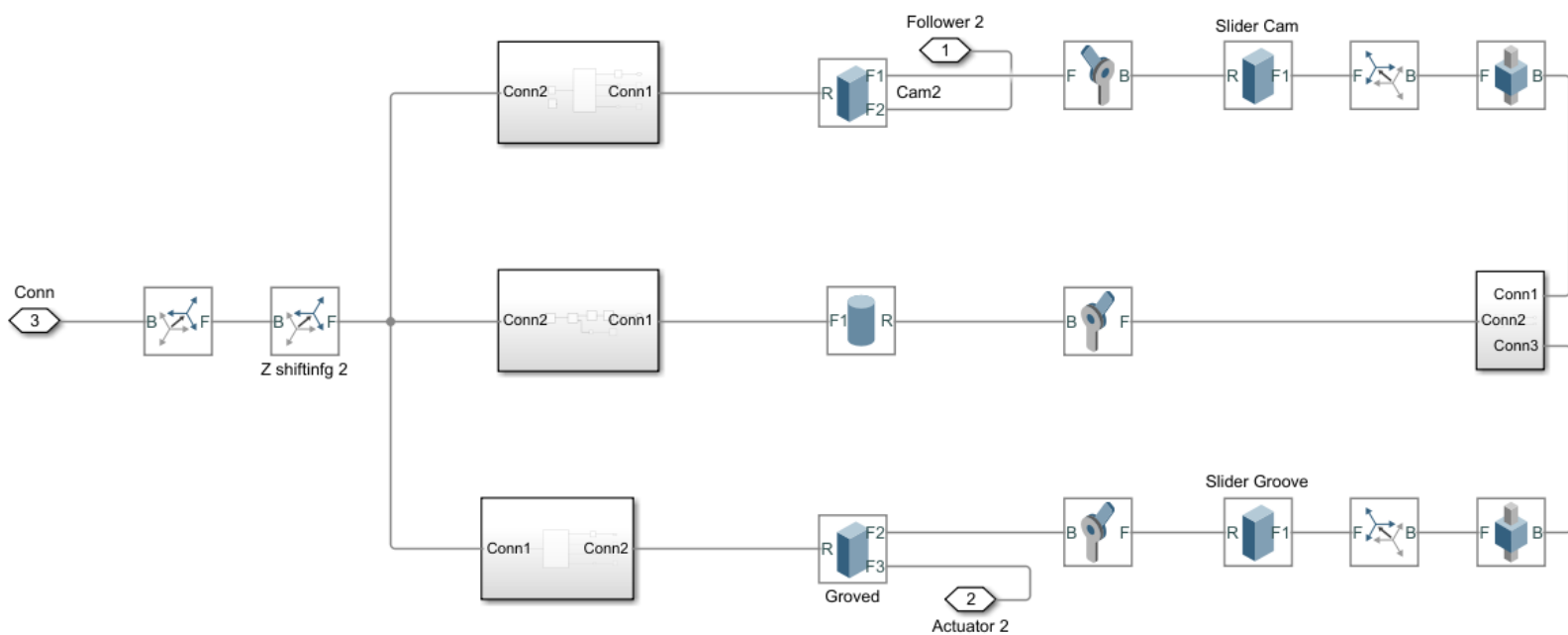


Figure (3-28) Unit two

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

The outcomes of the IVT system under consideration's utilizing theoretical analysis and simulation are provided and thoroughly examined in this chapter. The kinematic analysis for the IVT system is provided by the theoretical analysis discussed previously in chapter three. The system was modelled using MATLAB Simscape software for the simulation research that was given in chapter four. Using this package to build the system model is regarded as a significant accomplishment. This is because this software has high functionality features built in. A study of the theoretical and simulation results will be shown by figures and tables and discussed in this chapter. In simulation, the IVT system should be fully modelled in order to simulate the practical prototype. The simulation scheme goes beyond that it can also provide a complete dynamic representation of the system.

4.2 Theoretical & simulation results

4.2.1 Constant-constant velocity cam profile

This part will show displacement, velocity and acceleration of theoretical and simulation with constant – constant cam profile during two cycles of the cam.

Figures (4-1, 4-2, and 4-3) show the displacement, velocity, and acceleration respectively for a single unit during two cycles, each cycle lasts about 6.28 seconds.

In (5-3), it can be seen that the acceleration value increases toward infinity at periods (0 & 6.28 seconds) for positive infinity and (3.14 & 9.42 seconds) for negative infinity, at the start of both outworks and return strokes. The rapid change in velocity causes this behavior. This is the reason behind choosing a different kind of cam profile for the return stroke, which will be covered in the next section. Another

problem that is apparent is that the follower's velocity is going in the other direction during the return stroke. In chapter three (3.6 Ratchet), this subject was already discussed. Therefore, for continuous power transmission, several units (at least two) are required, as can be shown in the next section. It can be also noticed in these figures that the results of simulation and theoretical analysis are very compatible.

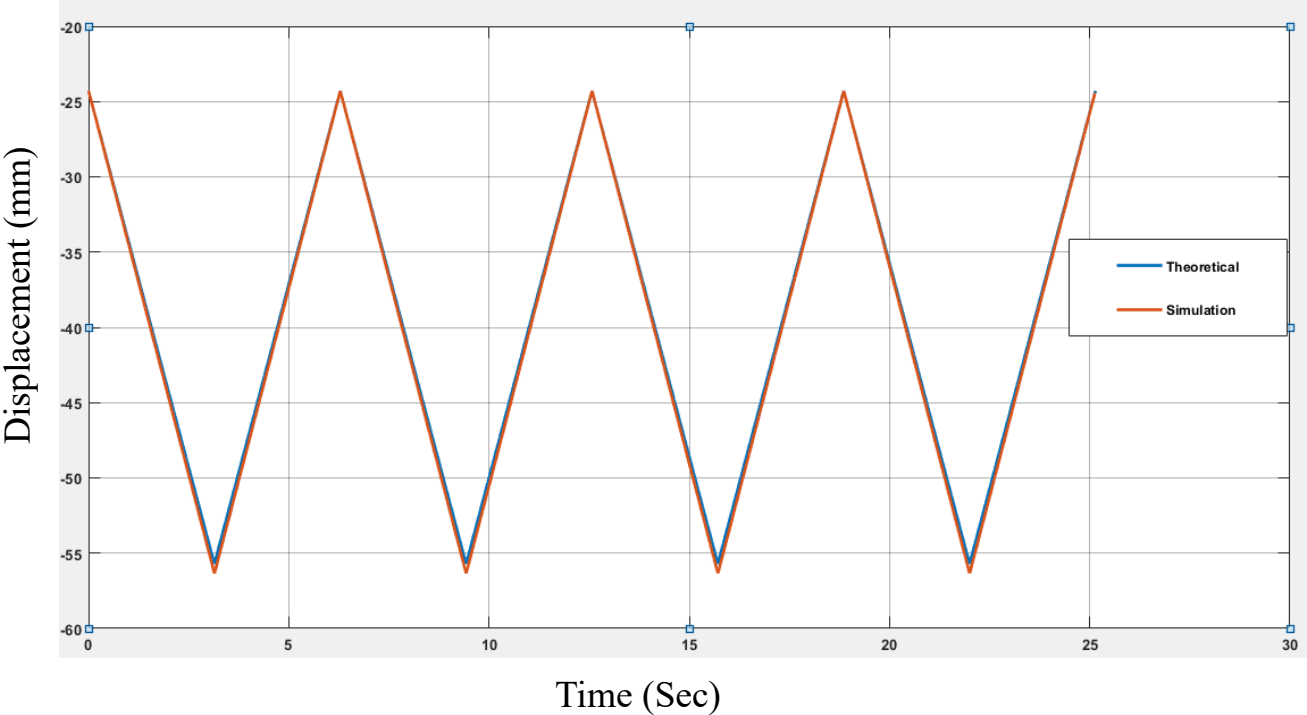


Figure (4-1) Displacement of Theoretical and simulation of Constant- Constant cam profile

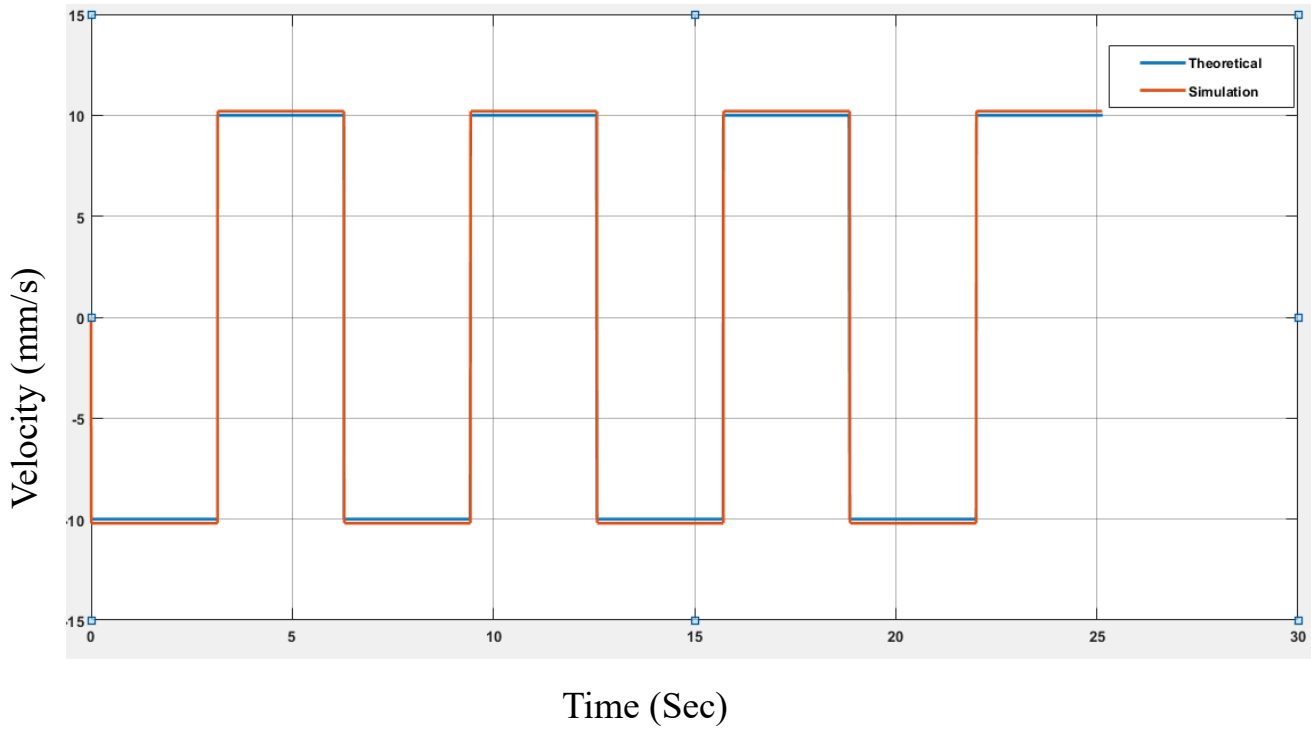


Figure (4-2) Velocity of theoretical and simulation of constant- constant cam profile

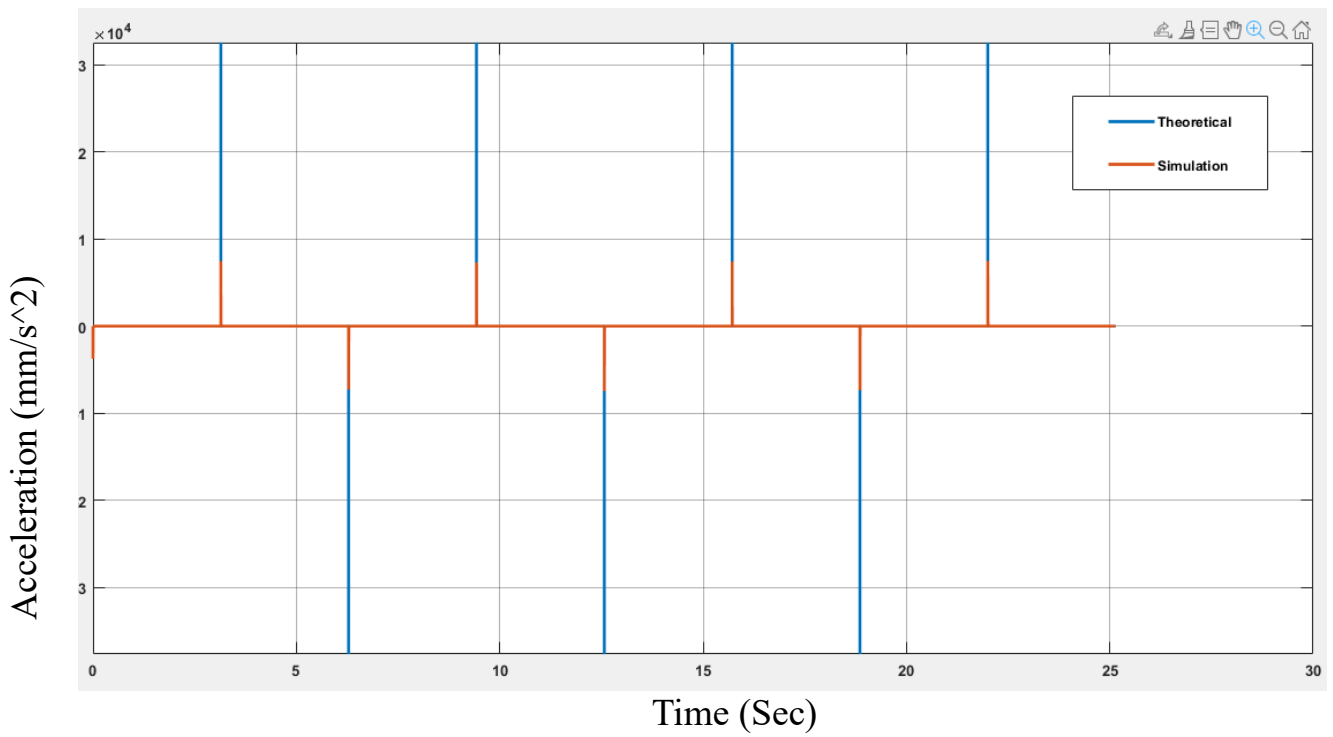


Figure (4-3) Acceleration of Theoretical and simulation of Constant- Constant cam profile

4.2.2 Constant velocity-polynomial cam profile

A combined cam profile of constant and fifth degree polynomials has been chosen as an alternative to the constant – constant velocity which has limitations at the time of changing the stroke this is discussed in details in chapter three.

Figures (5-4), (5-5) and (5-6) show smooth curves of motion and has a constant value for displacement, velocity and acceleration respectively.

This type Constant-polynomial cam profiles can be designed to achieve a variety of different motion profiles, including linear, parabolic, and cubic motion. The specific motion profile that is achieved is determined by the coefficients of the polynomial function.

Another advantages of constant-polynomial cam profiles is that they are relatively easy to design and manufacture. Also, they can be used to achieve a wide range of motion profiles.

However, there are also some disadvantages to constant-polynomial cam profiles. One disadvantage is that they can produce high accelerations which can lead to vibration and noise in the system. Another disadvantage is that they can be sensitive to manufacturing errors.

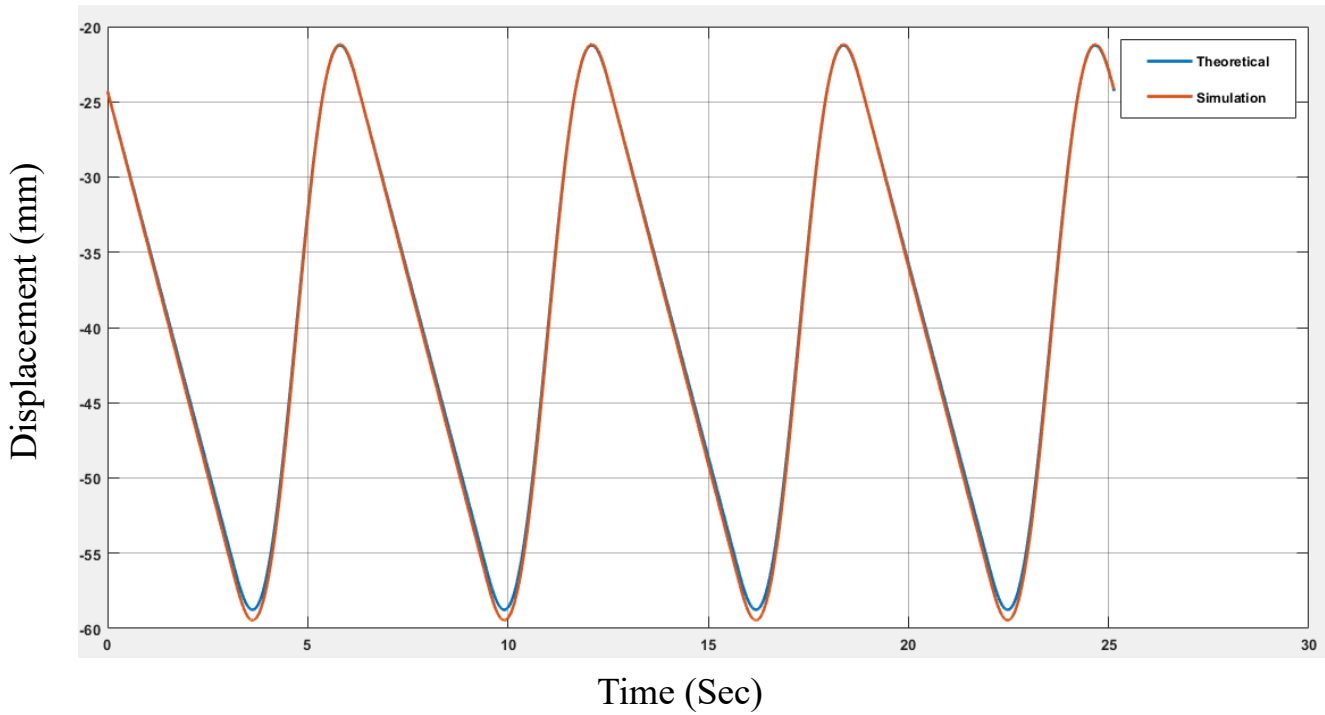


Figure (4-4) Displacement of theoretical and simulation of constant polynomial profile

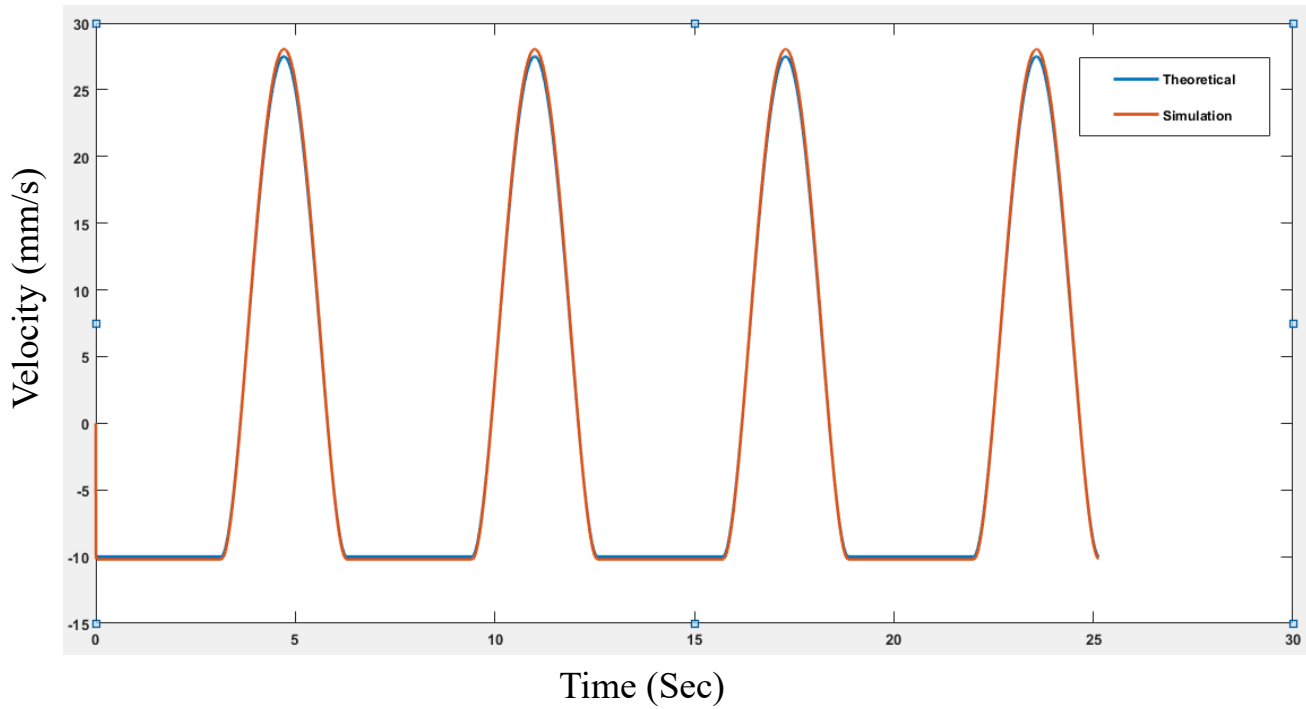


Figure (4-5) Velocity of theoretical and simulation of constant polynomial profile

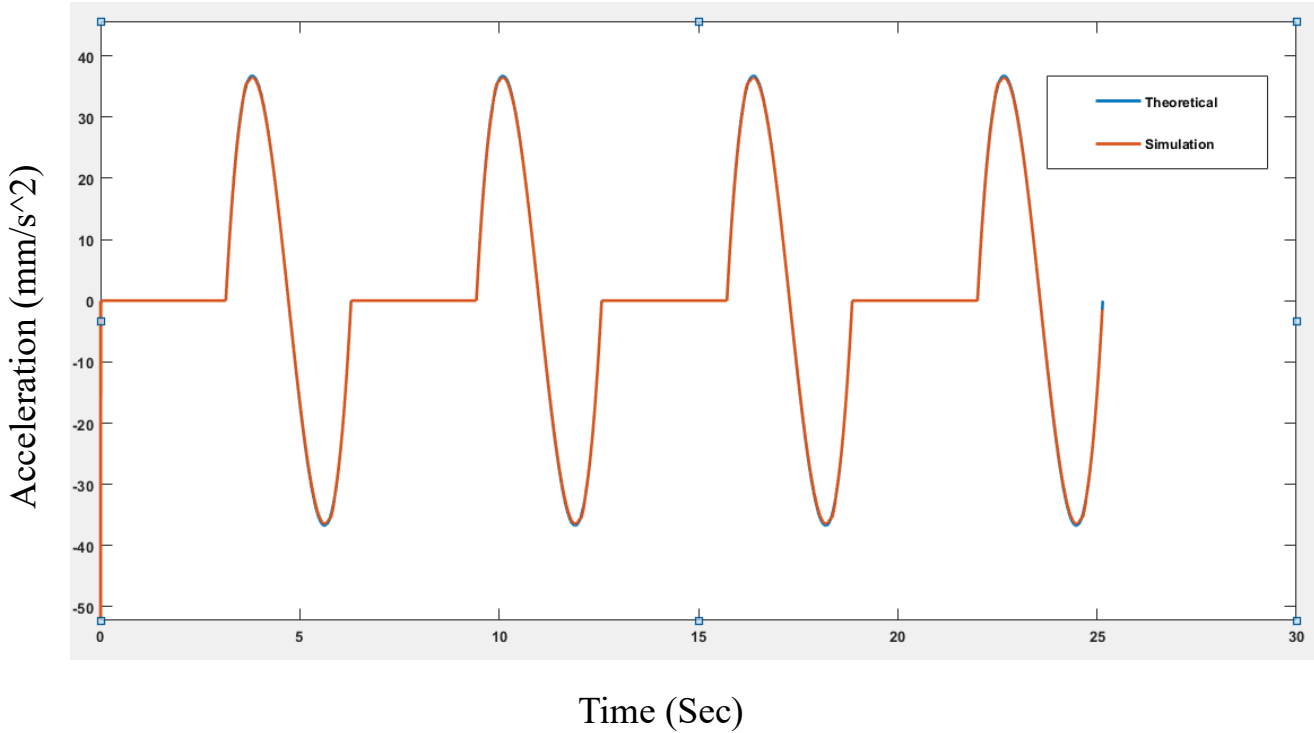


Figure (4-6) Acceleration of theoretical and simulation of constant polynomial profile

4.3 Alterable slotted link

This part is important in this mechanism because it designed in a way that can easily moves upward and downward along its axis by pin-slot joint and during this motion it can change the ratio of the transmission so it can be at fixed positions point or continuously change in the position of this link and this will give a change in transmission ratio as well.

4.3.1 constant velocity – constant velocity cam profile

The figures (4-7) show the angular displacement, velocity and acceleration of the alterable slotted link during two cycles of cam for two units. The problem of using constant-constant cam profile is also appeared here for the motion of slotted link it can be noticed that the curves have a sharp edge between any two strokes and this can lead to a high vibration of the whole mechanism which might lead to failure,

also, high drop in velocity because of sudden change between forward stroke and return stroke of cam profile

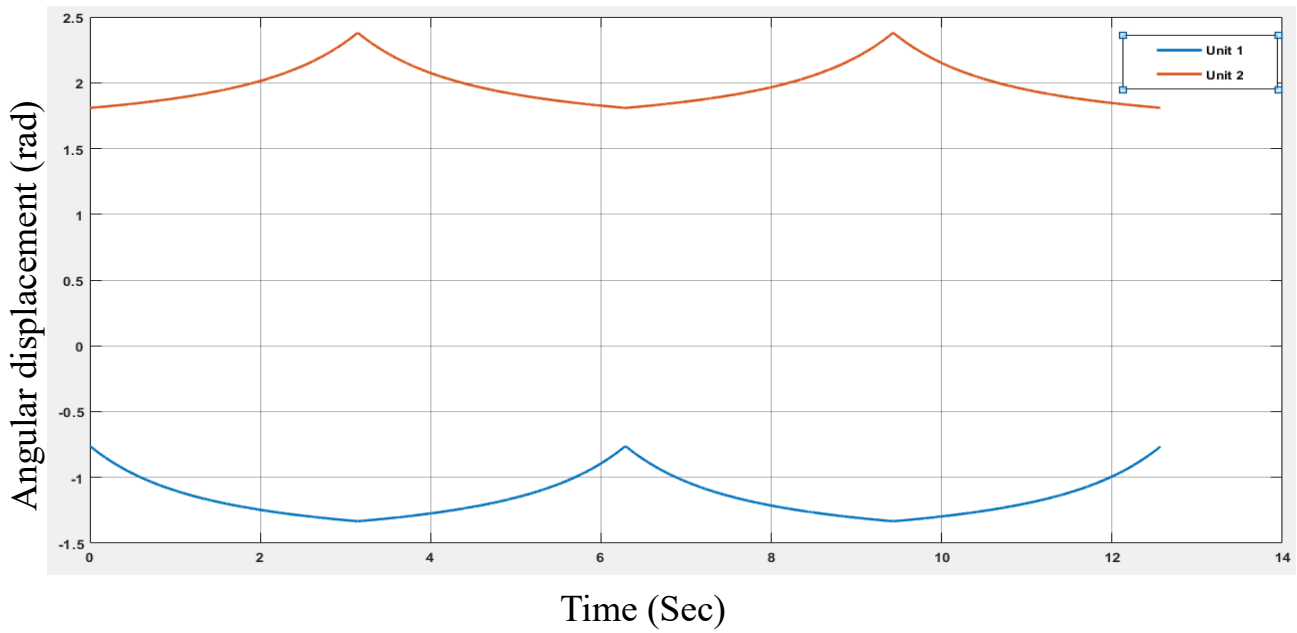


Figure (4-7) Angular displacement of alterable slotted link for two units

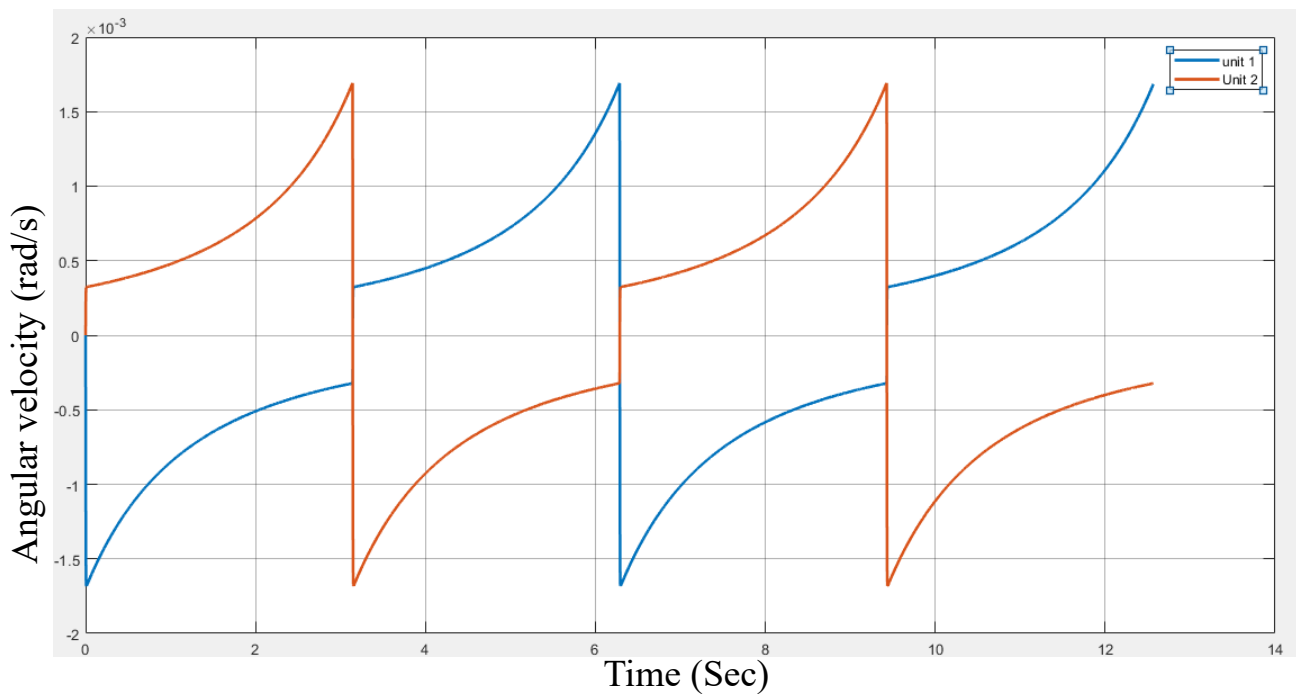


Figure (4-8) Angular velocity of alterable slotted link

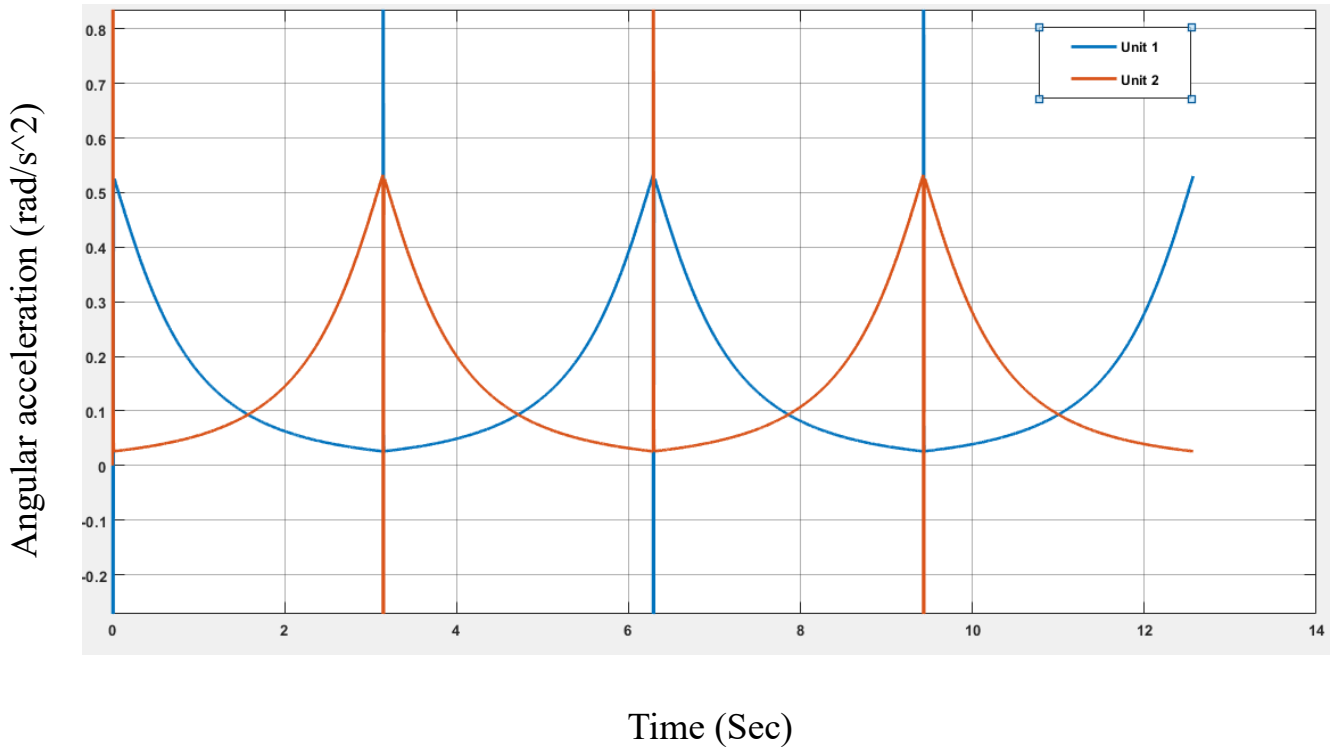


Figure (4-9) Angular acceleration of alterable slotted link

4.3.2 constant velocity – fifth degree polynomial cam profile

By using this cam profile, the curves now have a smooth profile with no sharp peaks which makes the motion easier and more sensible, the curves below show the angular displacement, velocity and acceleration of two units

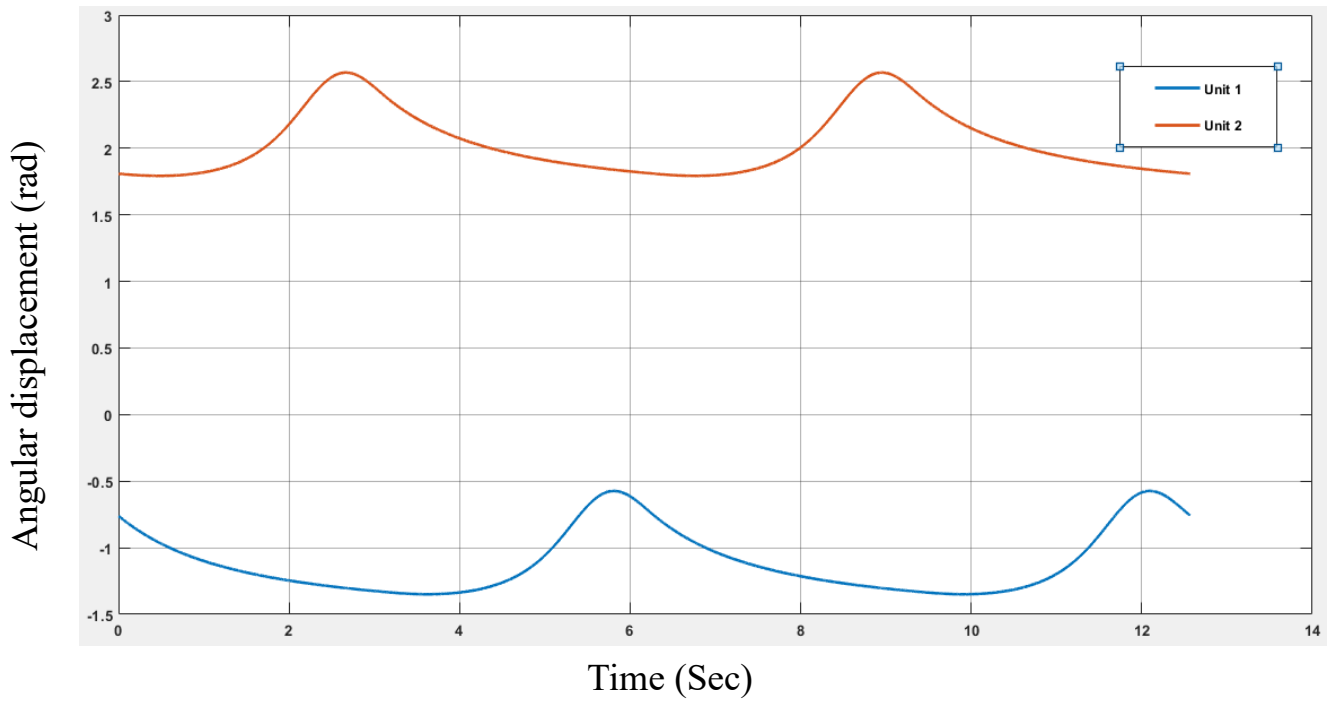


Figure (4-10) Angular displacement of alterable slotted link for two units

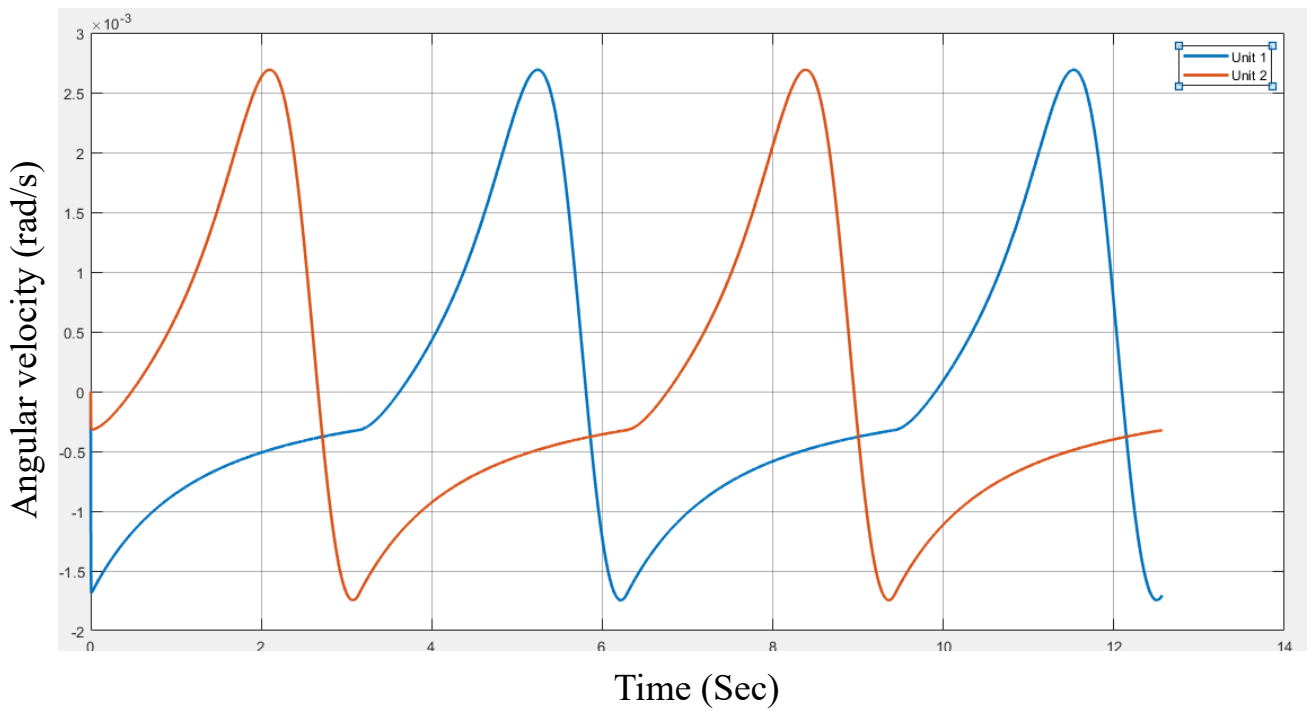


Figure (4-11) Angular velocity of alterable slotted link for two units

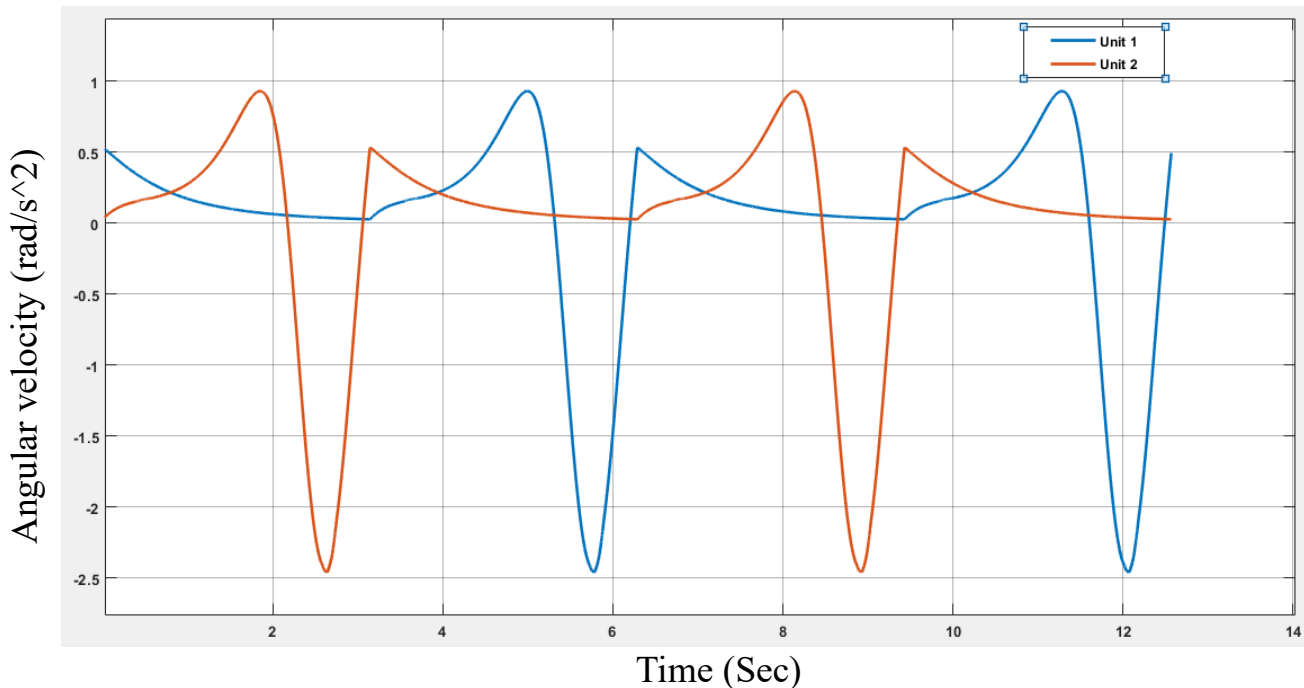


Figure (4-12) Angular acceleration of alterable slotted link for two units

4.4 Output results based on fixed alterable position

The output of the IVT depends on the alterable position for the same input, in this section the alterable joint was positioned in three different values (2.5, 3, 3.5) cm used to test the output of the IVT for single unit and two units.

4.4.1 Single unit results

As mentioned before, by changing the vertical position of the alterable slotted link can change the transmission ratio between output and input shafts and that can also be seen in the motion of grooved wheel actuator horizontal motion. The figures (4-13), (4-14) and (4-15) below showing three different values of alterable slotted link (y) and the result is displacements, velocities and accelerations respectively for the same input. The output has a different value of amplitude also the acceleration goes to infinity this because of stepped vertical velocity of alterable link.

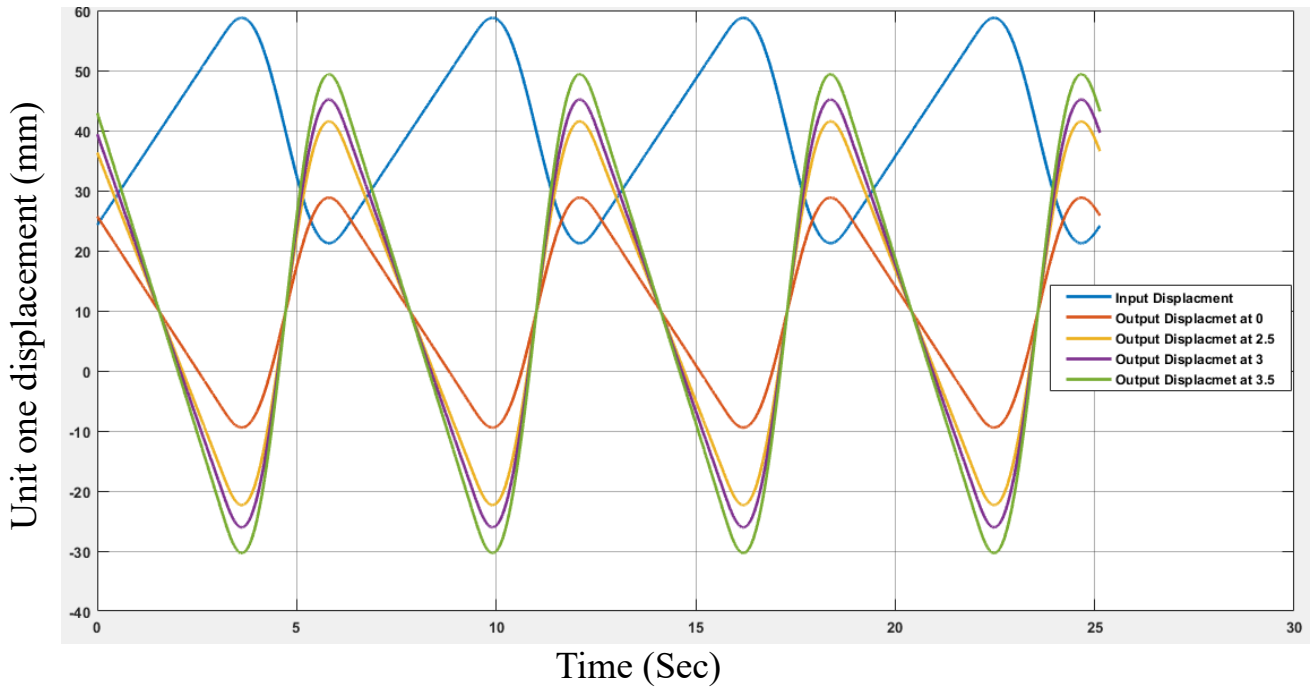


Figure (4-13) Four output displacements for the same input for single unit (cm)

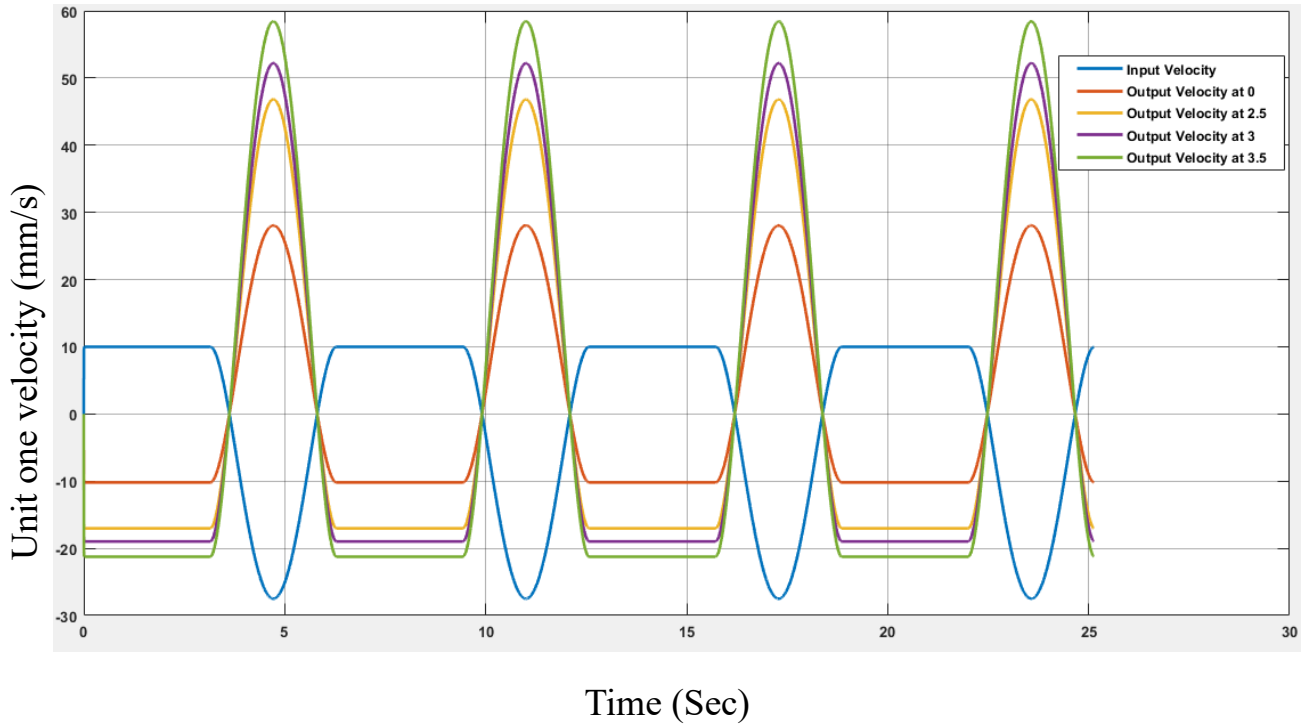


Figure (4-14) Three output velocities for the same input for single unit(cm)

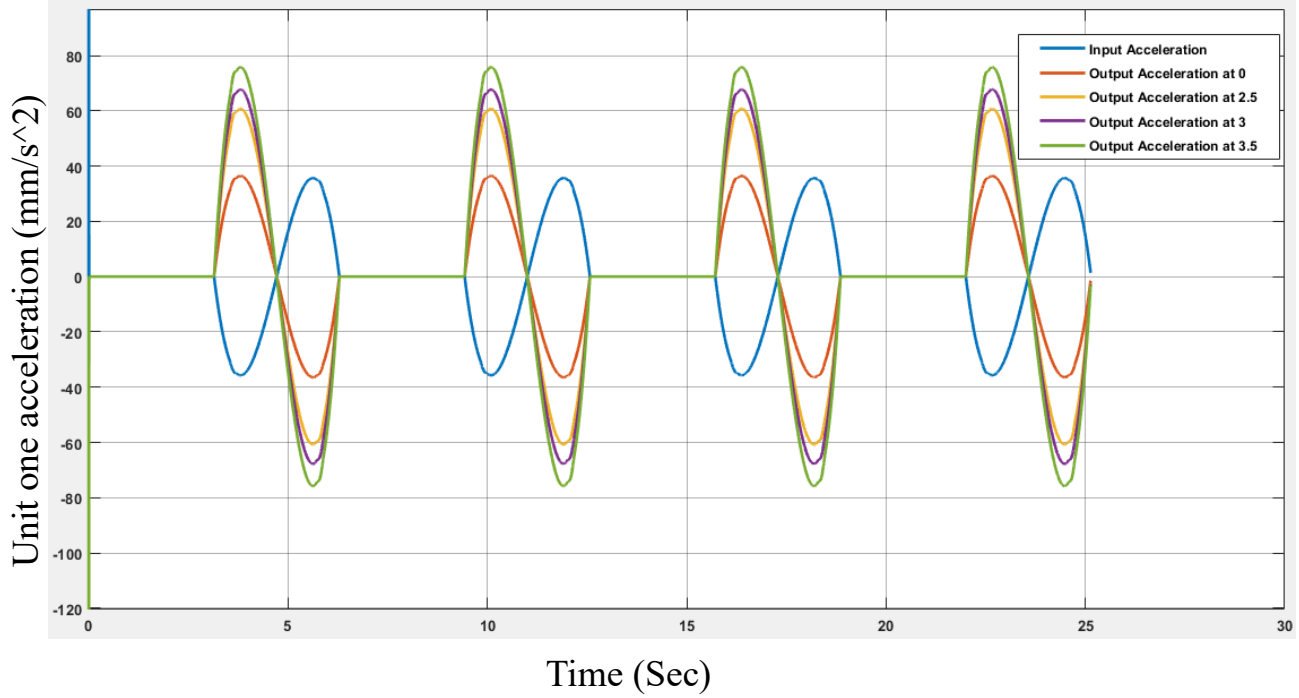


Figure (4-15) Three output accelerations for the same input for single unit (cm)

4.4.2 Two Units Results

The output displacements, velocities and accelerations of unit two for these y values are shown in the figures (4-16), (4-17) and (4-18) the phase shift between the two units is clearly shown to archive the continuously of motion done.

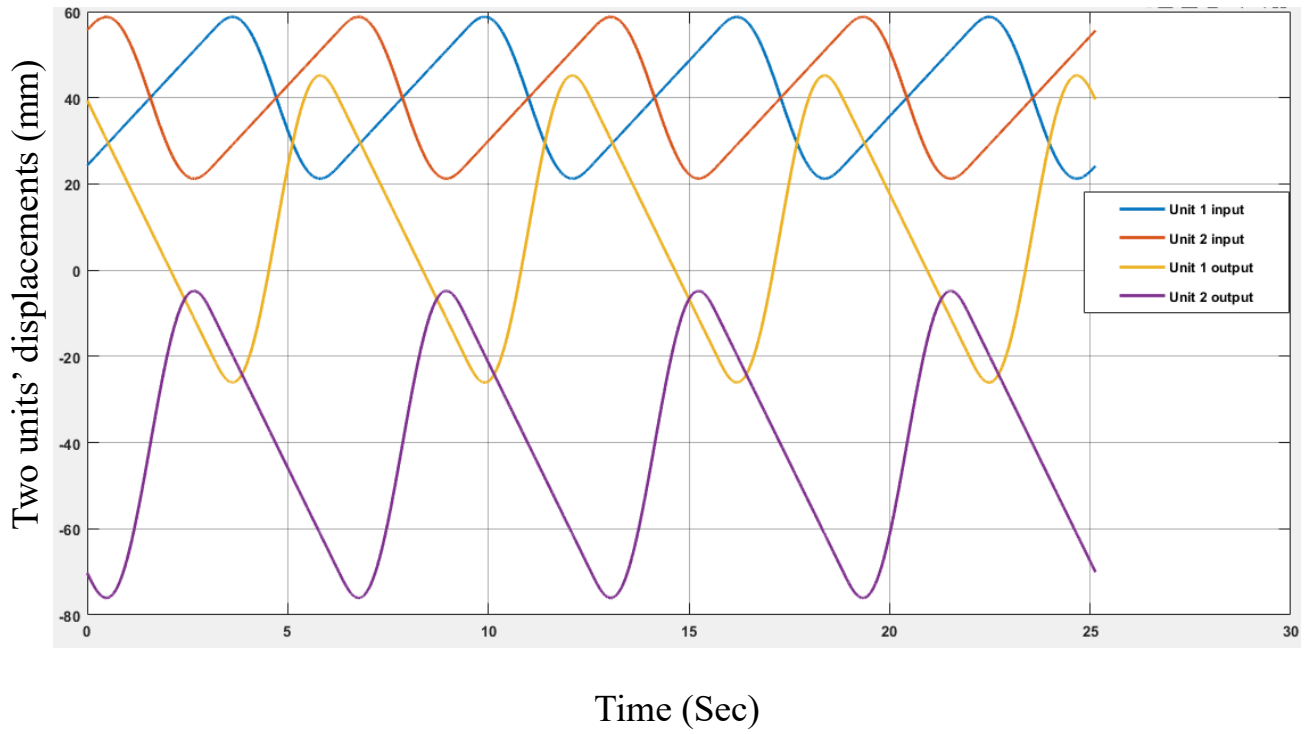


Figure (4-16) Input and output displacements for two units at particular alterable vertical position (7cm)

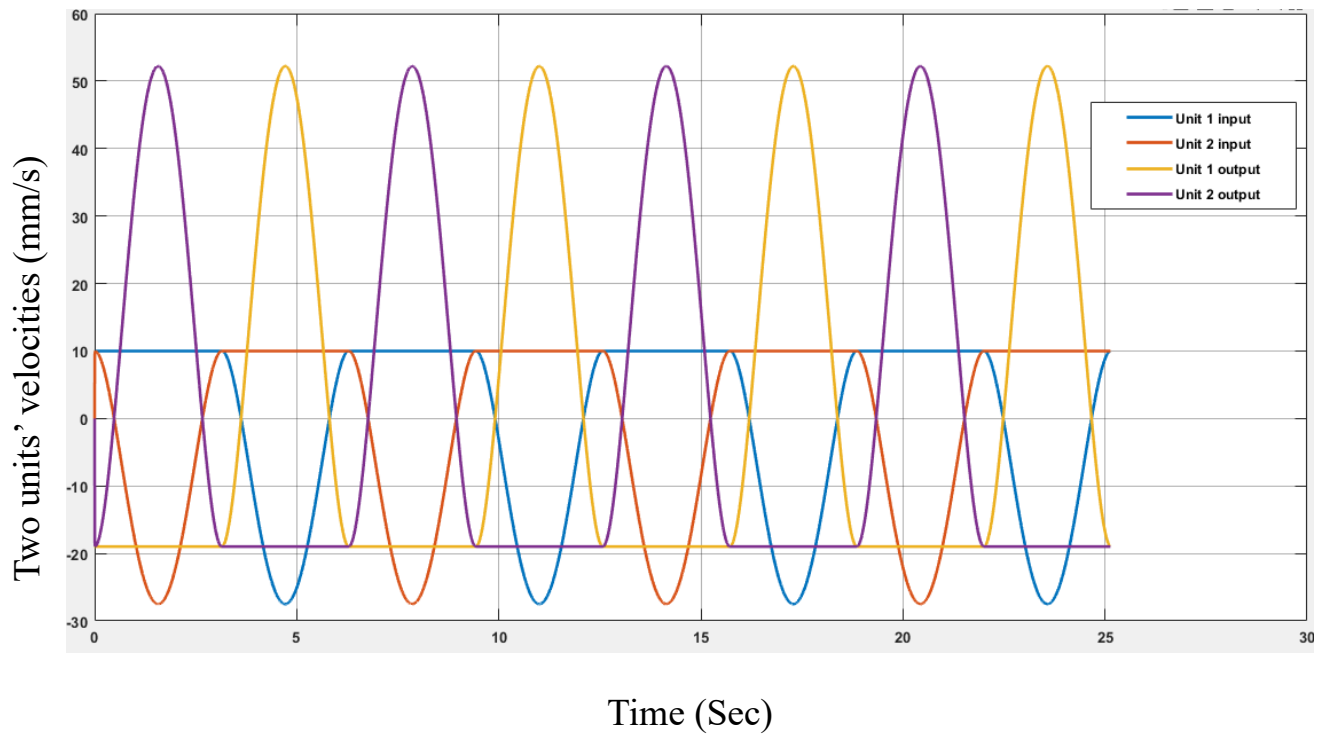


Figure (4-17) Input and output velocity for two units at particular alterable vertical position (7cm)

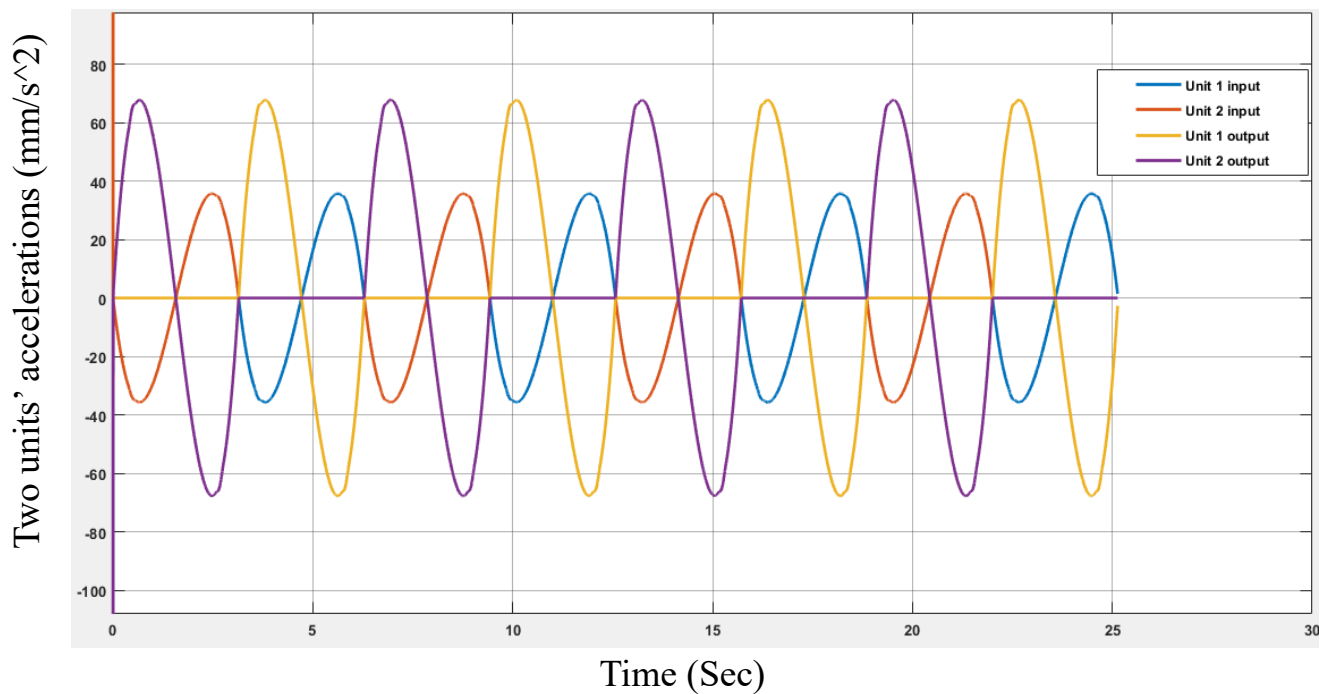


Figure (4-18) Input and output acceleration for two units at particular alterable vertical position (7cm)

4.5 Output results based on moving alterable

In the previous section, the alterable was set to be fixed at different y positions, and the results gained was in constant profile for all parameter, now in this section, a constant velocity is given for the alterable using block called ramp. This input provides smooth, constant and continues moves of the alterable joint. this can give a constant increase in three parameters measured Also, three values were tested in this section (0.2, 0.25, 0.3) cm/s.

4.5.1 Single unit

Displacement, velocity and acceleration diagrams are shown in figures (4-19), (4-20) and (4-21) respectively.

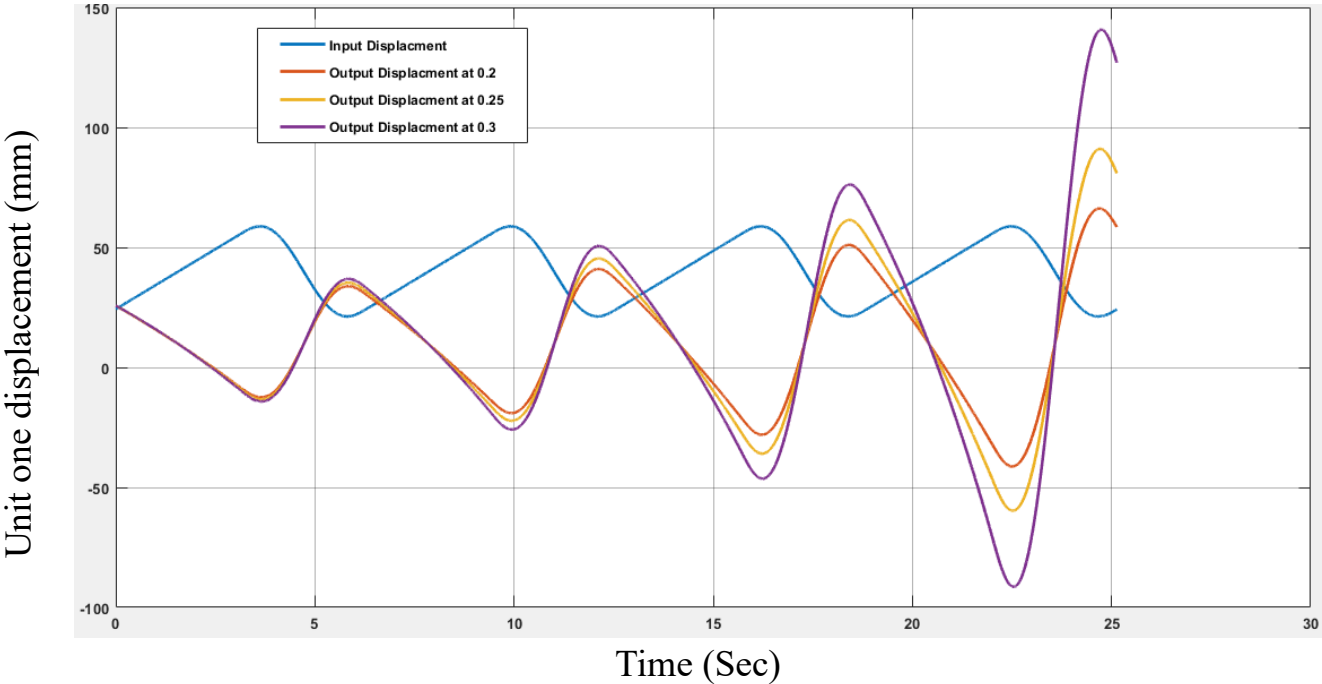


Figure (4-19) Three output displacements for the same input for single unit (cm/s)

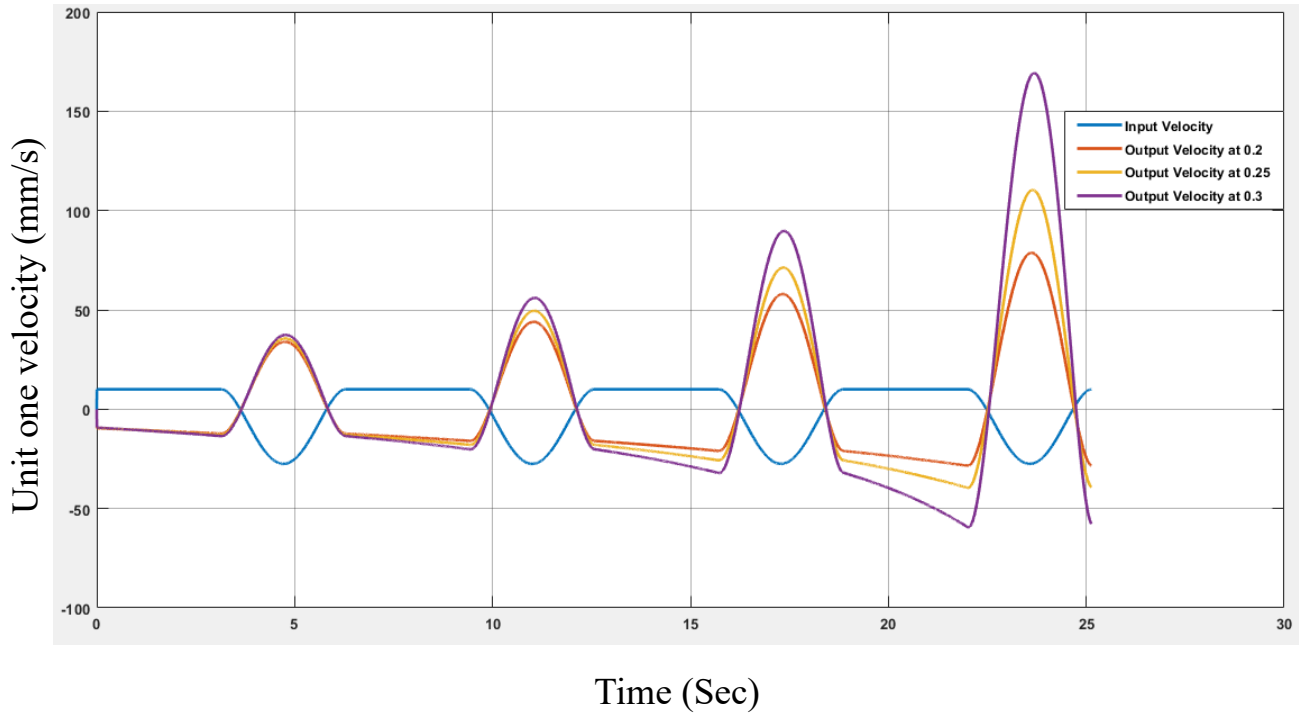


Figure (5-20) Three output velocities for the same input for single unit (cm/s)

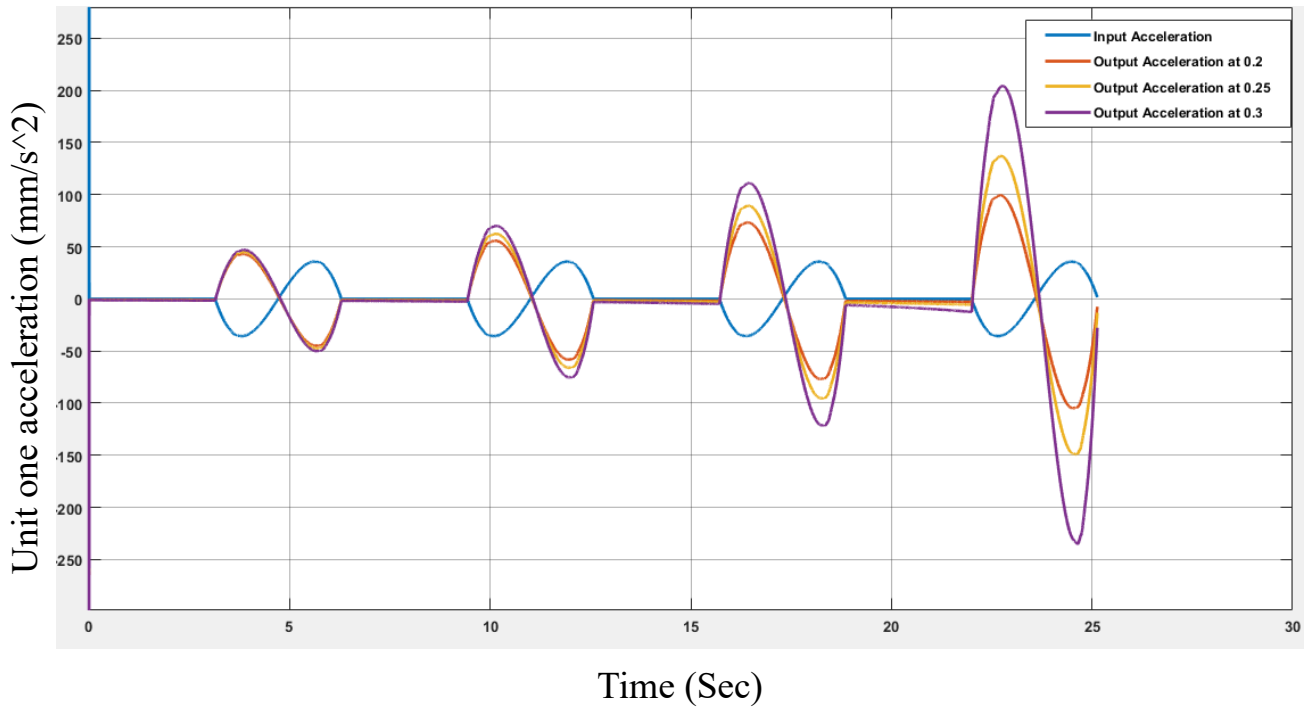


Figure (4-21) Three output accelerations for the same input for single unit (cm/s)

4.5.2 Two Units Results

Again, for two units the displacement, velocity and acceleration are shown in figures below

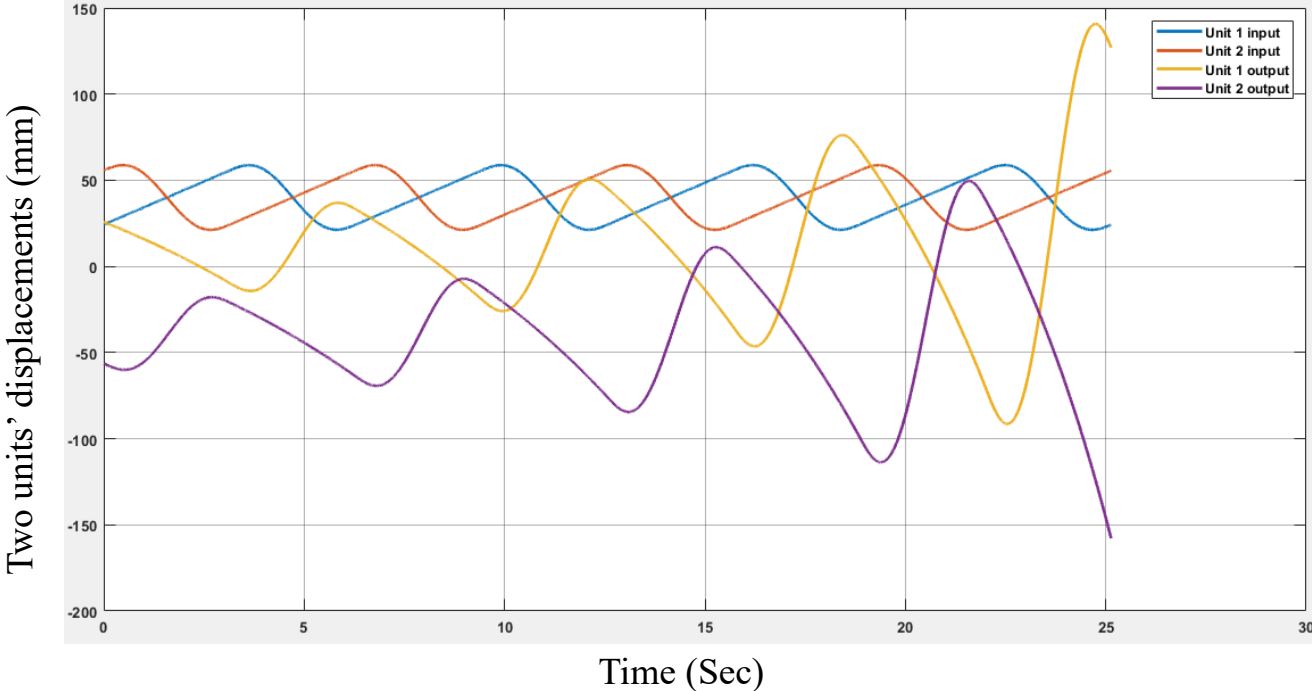


Figure (4-22) Two units output displacements for the same input

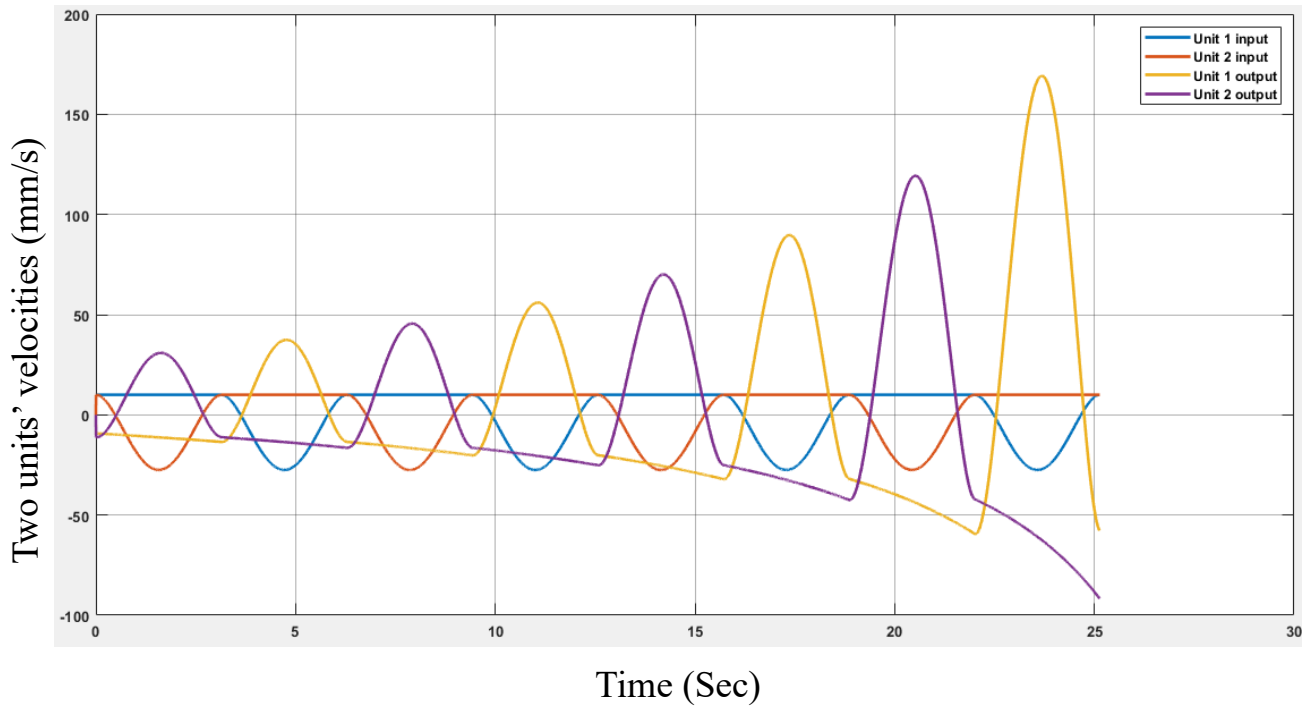


Figure (5-23) Two units output velocities for the same input

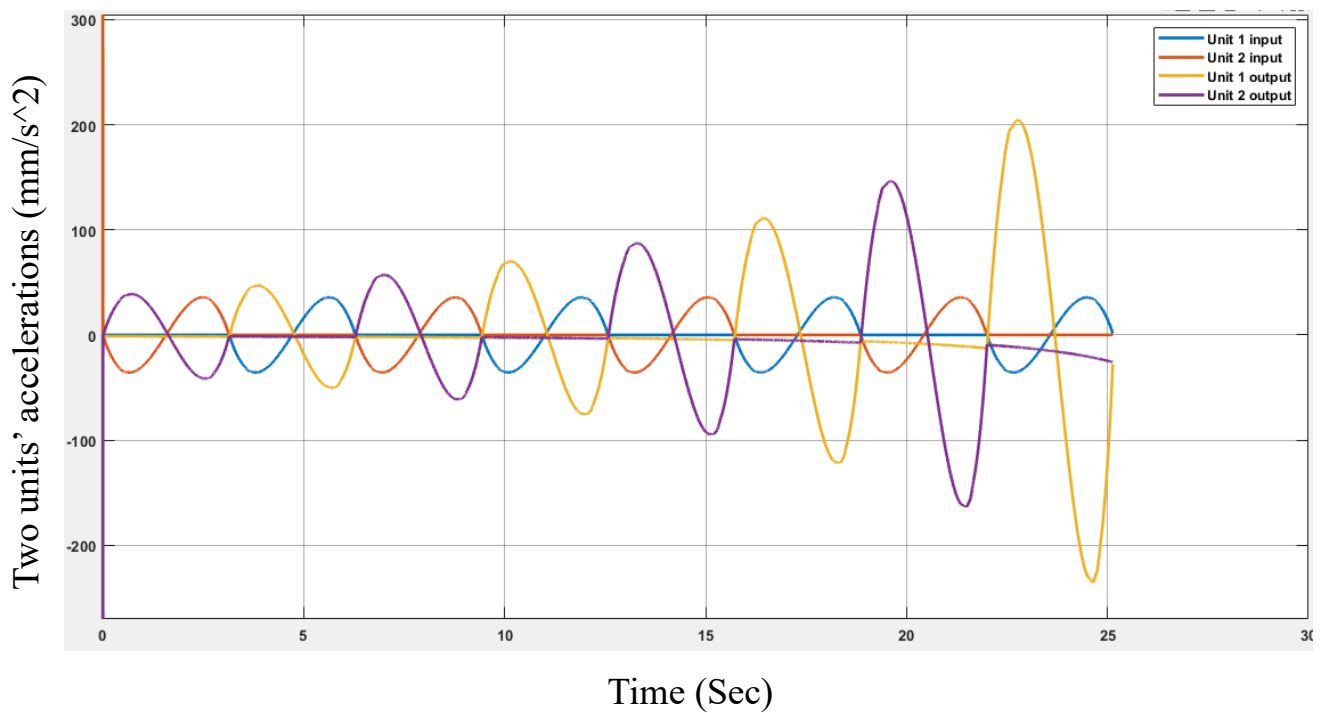


Figure (5-24) Two units output accelerations for the same input

CHAPTER FIVE:

CONCLUSION AND FUTURE WORKS

5.1 Conclusions and remarks

A recent model of transmission systems has been studied using theoretical and simulation analysis. A high focus was given to the simulation in order to have many cases to discuss by using good environment software (MATLAB Simscape). This simulation was validated with the theoretical analysis where almost no errors have been indicated. The following conclusions can be presented:

1. The system gives an infinitely variable transmission between the input and output of the system.
2. Using a constant-constant velocity cam profile introduces a high acceleration in the system approaches to infinity which leads to a very large amount of loading through the system elements and the contact zones.
3. Using a combined cam profile of constant velocity- fifth degree polynomial gives a smooth variation in displacement, velocity and acceleration through the system.
4. The vertical velocity of the alterable has a significant effect on the system output.
5. The system output increased gradually for increasing the vertical position of the alterable increased with zero velocity. While a small jump is introduced during the vertical movement when stroke changes between the units.
6. Using a ratchet mechanism inside the grooved wheels give one way motion, which avoid the negative value of motion that is unwanted for the output shaft.

5.2 Recommendations and future work

1. More cam profiles might be examined for the current IVT.
2. Different velocity functions of the vertical motion of the alterable can be studied.
3. The force analysis at each part of the system and at the contact zones might be investigated in detail.
4. Studying the effect of the geometry at the end of the followers in the contact zones.
5. A deep analysis of the ratchets will be useful for this type of systems.
6. Studying the effect of the number of units and the overlap of these units in this kind of IVT.
7. Theoretical understanding of the system using fully multibody dynamic analysis will be an efficient scheme for this type of system.

REFERENCES

1. Julio, G. and J.-S. Plante, An experimentally-validated model of rubber-belt CVT mechanics. *Mechanism and Machine Theory*, 46(8): p. 1037-1053,2012.
2. Tyreas, G.C. and P.G. Nikolakopoulos, Development and friction estimation of the Half-Toroidal Continuously Variable Transmission: A wind generator application. *Simulation Modelling Practice and Theory*. 66: p. 63-80,2016.
3. Verbelen, F., Derammelaere, S., Sergeant, P., & Stockman, K.. A comparison of the full and half toroidal continuously variable transmissions in terms of dynamics of ratio variation and efficiency. *Mechanism and Machine Theory* ,121, 299-316, (2018).
4. OLYAEI, Abbas. Novel continuously variable transmission mechanism. *SN Applied Sciences*, 1.9: 1-7, 2019
5. ALIUKOV, Sergei; KELLER, Andrei; ALYUKOV, Alexander. Inertial Continuously Variable Transmissions and Ways to Improve Their Performance. *SAE International Journal of Engines*, 11.2018-01-1059, 2018.
6. Wang, G., Song, Y., Wang, J., Xiao, M., Cao, Y., Chen, W., & Wang, J.. Shift quality of tractors fitted with hydrostatic power split CVT during starting. *Biosystems Engineering*, 196, 183-201, (2020).
7. MANGIALARDI, L.; MANTRIOTA, G. The advantages of using continuously variable transmissions in wind power systems. *Renewable Energy*, 2.3: 201-209,1992.
8. Hamad, Muhaiman Faleh. Study and Development of Cam Based Infinitely Variable Transmission. Diss. University of Babylon, 2021.

9. Tanaka, H., and H. Machida. "Half-toroidal traction-drive continuously variable power transmission." *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology* 210.3 (1996): 205-212.
10. Belfiore, Nicola Pio, and G. De Stefani. "Ball toroidal CVT: a feasibility study based on topology, kinematics, statics and lubrication." *International Journal of Vehicle Design* 32.3-4 (2003): 304-331.
11. Carbone, Thomas A., and Donald D. Tippett. "Project risk management using the project risk FMEA." *Engineering management journal* 16.4 (2004): 28-35.
12. Wang, S. M., Li, Z., Wang, X. Y., & Li, X. C.. Development of the spheretoroidal continuously variable transmission. In *Advanced Materials Research* (Vol. 986, pp. 1315-1318). Trans Tech Publications Ltd, (2014).
13. Verbelen, Moira, Michael E. Weale, and Cathryn M. Lewis. "Cost-effectiveness of pharmacogenetic-guided treatment: are we there yet?." *The pharmacogenomics journal* 17.5 (2017): 395-402.
14. Verbelen, Florian, et al. "A comparison of the full and half toroidal continuously variable transmissions in terms of dynamics of ratio variation and efficiency." *Mechanism and Machine Theory* 121 (2018): 299-316.
15. Milazzo, M., Moretti, G., Burchianti, A., Mazzini, D., Oddo, C. M., Stefanini, C., & Fontana, M. A passively regulated full-toroidal continuously variable transmission. *Meccanica*, 55(1), 211-226. (2020).
16. MARATHE, Kunal S.; WAKCHAURE, Vishnu D. Performance Analysis of Single Ball Traction Drive for Continuously Variable Transmission. (2020).
17. Kot, A., & Łatas, W. (2021). Experimental and theoretical investigation of CVT rubber belt vibrations. *Open Engineering*, 11(1), 1196-1206.

18. Yukawa, T. A DESIGN FOR CONTINUOUSLY VARIABLE TRANSMISSION CONSISTING OF LINKS, CRANKS, CAMS, AND FREEWHEELS. *control design*, 15, 16.
19. Faleh, M., Al-Hamood, A., & Majeed, M. H. (2022). Cam based Infinitely Variable Transmission Theoretic Modelling. In *IOP Conference Series: Earth and Environmental Science* (Vol. 961, No. 1, p. 012091). IOP Publishing.
20. Mangialardi, L., and G. Mantriota. "The advantages of using continuously variable transmissions in wind power systems." *Renewable Energy* 2.3 (1992): 201-209.
21. Mangialardi, L., and G. Mantriota. "Automatically regulated CVT in wind power systems." *Renewable Energy* 4.3 (1994): 299-310.
22. Chen, T. F., D. W. Lee, and Cheng-Kuo Sung. "An experimental study on transmission efficiency of a rubber V-belt CVT." *Mechanism and machine theory* 33.4 (1998): 351-363.
23. Julio G and Plante JS. An experimentally-validated model of rubber-belt CVT mechanics. *Mech Mach Theory* 2011; 46: 1037–1053.
24. Karam A and Play D. A discrete analysis of metal-V belt drive, 2013, <https://arxiv.org/ftp/arxiv/papers/1301/1301.5595.pdf>
25. Tsuchiya, Eiji, and Eiji Shamoto. "Pulse drive: a new power-transmission principle for a compact, high-efficiency, infinitely variable transmission." *Mechanism and Machine Theory* 118 (2017): 265-282.
26. Kembraum AS, Kitchell M and Crittenden M. An ultracompact infinitely variable transmission for robotics. In: *Proceedings of the 2017 IEEE international conference on robotics and automation (ICRA)*, Singapore, 29 May–3 June 2017, pp.1800–1807. New York: IEEE.

27. Naclerio ND, Kerst CF, Haggerty DA, et al. Low-cost, continuously variable, strain wave transmission using gecko-inspired adhesives. *IEEE Robot Autom Lett* 2019; 4: 894–901.
28. Laxman, Ramavath; Scholar, P. G. Comparative Analysis Of A manual Gear Box With Continuously Variable Transmission Of A Car.
29. CERVANTES-CULEBRO, Hector; CRUZ-VILLAR, Carlos Alberto; PALMAMARRUFO, Orlando. Infinitely variable transmission with orbital pulleys. *Advances in Mechanical Engineering*, 11.10: 1687814019883717, 2019.
30. Agrawal, A. (2021). Review on Continuous Variable Transmission (CVT). In *Integrated Emerging Methods of Artificial Intelligence & Cloud Computing* (pp. 494-502). Cham: Springer International Publishing.
31. Peschke, T., Münch, P., & Gorges, D. (2021). Model Predictive Control for Combine Harvesters using Geospatial Data. In *Commercial Vehicle Technology 2020/2021: Proceedings of the 6th Commercial Vehicle Technology Symposium* (pp. 63-76). Springer Fachmedien Wiesbaden.
32. BENITEZ, F. G.; MADRIGAL, J. M.; DEL CASTILLO, J. M. Infinitely variable transmission of ratcheting drive type based on one-way clutches. *J. Mech. Des.*, 126.4: 673-682. 2004.
33. M ABOOD, Amjad. A novel cam-based infinitely variable transmission. *Journal of Kerbala University*, 6.2: 61-74, 2010.
34. Morales, F. and Benitez, F., 2014, Basic Conceptual Designs for Rectifiers of Inertial Transmissions, SAE Technical Paper 2014-01-1737, <https://doi.org/10.4271/2014-01-1737>.
35. CHOUDHARY, R., PROJECT REPORT ON DESIGN AND FABRICATION OF MINIATURE OF CONTINUOUSLY VARIABLE TRANSMISSION. 2012.

36. Al-Hamood, A., Jamalia, H., Imran, A., Abdullah, O., Senatore, A., & Kaleli, H.. Modeling and theoretical analysis of a novel ratcheting-type cam-based infinitely variable transmission system. *Comptes Rendus Mécanique*,347(12),891-902, (2019).
37. Bhusal, K.P., StudYig the functionality of infinitely variable drive using multibody dynamics simulation approach. 2017.
38. OLYAEI, Abbas. Novel continuously variable transmission mechanism. *SN Applied Sciences*, 1.9: 1-7, 2019.
39. Al-Hamood, A., Jamali, H. U., Abdullah, O. I., & Schlattmann, J.. The Performance of One-Way Clutch in a Cam-Based Infinitely Variable Transmission. In *IOP Conference Series: Materials Science and Engineering*, (Vol. 671, No. 1, p.012008). IOP Publishing, (2020).

الخلاصة

ناقل الحركة المتغير باستمرار (CVT) هو نظام يسمح بالتغيير المستمر السلس لنسبة النقل بين عنصرين دوارين CVT. هي مجموعة فرعية من IVT ؛ عمليات نقل متغيرة بلا حدود والتي يمكن أن تنتج نسبة نقل سلسة بما في ذلك القيمة الصفرية. هذه على النقيض من عمليات النقل التقليدية التي تحتوي عادةً على عدد منفصل ومحدود من نسب النقل أو كما هو معروف بأسم نسبة التروس. بدأ استخدام نظام CVT ليكون بديلاً لمجموعات التروس التقليدية في المركبات، حيث يمكنه توفير تسارع أكثر سلاسة واقتصاداً أفضل في استهلاك الوقود.

في هذه الرسالة، تمت دراسة IVT المعتمد على الحدبة بالتفصيل باستخدام التحليل النظري ونموذج المحاكاة. يحتوي IVT الحالي على وحدتين، تتكون كل وحدة من حدبة، وتابع، ووصلة مشقوقة قابلة للتغيير، وعجلة محززة، وتابع عجلة محززة. يتكون شكل الحدبة المختار من جزأين هما السرعة الثابتة التي تمثل الشوط الأمامي وشوط متعدد الحدود لشوط العودة، وسيتم التحقيق في هذا في هذه الدراسة.

تم إجراء محاكاة النظام في الدراسة الحالية باستخدام برنامج Matlab Simscape حيث تم استخدام التحليل النظري للتحقق من صحة نموذج المحاكاة هذا. باستخدام برنامج Matlab Simscape ، حيث تم إنشاء مجسم كل عنصر بالتفصيل. ومن ثم يتم تجميع هذه العناصر باستخدام وصلات محددة متوفرة اعتماداً على الوصلات الفعلية في الأنظمة. يجب أيضاً ضبط مواقع هذه العناصر باستخدام الإطارات المحلية والتحويل الصلب لمطابقتها مع إطارات النظام العالمي.

أظهرت النتائج أنه يمكن تحقيق تباين سلس في الإخراج في مواضع مختلفة لنسبة الإرسال القابلة للتغيير. ومع ذلك، يمكن ملاحظة قفزة صغيرة في الإخراج أثناء تغيير الحد أثناء تحرك المتغير. يمكن حل هذه المشكلة عن طريق إضافة دولاب الموازنة إلى النظام. ويمكن أيضاً أن نستنتج أن تغيير الموقع العمودي وسرعة التغيير لهما تأثير كبير على مخرجات النظام.



جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة الميكانيكية

محاكاة وتحليل لمنظومة نقل الحركة بلا حدود تعتمد على مبدأ الحدبة

رسالة مقدمة الى قسم الهندسة الميكانيكية – جامعة كربلاء كجزء من متطلبات نيل درجة

الماجستير في الهندسة الميكانيكية

(ميكانيك تطبيقي)

من قبل

منيار حمدي عبدالحسن

بكلوريوس في الهندسة الميكانيكية 2019

المشرف:

أ.م.د. أمجد الحمود