

POLITECNICO DI MILANO

MASTER THESIS

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**Simulation and Optimization of an oven  
hinge mechanism through  
LMS-AMESim**

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*“I remember my mother’s prayers and they have always followed me. They have clung to me all my life.”*

Abraham Lincoln

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## *Abstract*

Dipartimento di Meccanica

Master Of Science

### **Simulation and Optimization of an oven hinge mechanism through LMS-AMESim**

by Milad AMINI HARANDI

This thesis describes the simulation and optimization of an oven hinge by means of the software LMS AMESim. The real hinge model helps us to select the elements of different libraries of the software namely “signal”, “mechanical”, “planar mechanic” and “cam and follower” besides, calculating the needed parameters for each icon.

After running the simulation the CAD models are imported in AMESim to have a realization of the assembly. Then an experiment is performed to discover the input load applied to the handle of the oven and find out about the values of velocity and acceleration after running the simulation. Optimization of the system is done based on minimizing the value of the integral between the squared difference of the velocity of the real model and the system. After performing the optimization via “genetic algorithm and “NLPQL method, the corresponding value of all implemented elements are obtained. Finally modeling of the power grasp (holding the handle of the oven) is done by an eight element circuit. The results of this section are compared with the experiment.

Questa tesi descrive la simulazione e ottimizzazione di una cerniera forno mediante il software LMS AMESim. Il modello di cerniera vera ci aiuta a selezionare gli elementi di erenti biblioteche del software e cio "segnale ", "meccanico", "meccanico planare " e "cam e seguace ". Inoltre, il calcolo dei parametri necessari per ogni icona. Dopo aver eseguito la simulazione dei modelli CAD sono importati in AMESim per avere un realizzazione del montaggio. Poi viene eseguito un esperimento per scoprire l'ingresso carico applicato alla maniglia del forno e nd conoscere i valori di velocit e accelerazione dopo l'esecuzione della simulazione. Ottimizzazione del sistema viene fatto sulla base minimizzando il valore dell'integrale tra il quadrato di erenza della velocit del vero modello e il sistema. Dopo aver eseguito l'ottimizzazione tramite algoritmo genetico e metodo NLPQL, il corrispondente valore di tutti gli elementi implementati sono ottenuti. Infine modellazione della presa di potenza (tenendo la maniglia del forno) fatto da un otto circuito elemento. I risultati di questa sezione sono confrontati con l'esperimento.

## *Acknowledgements*

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# Contents

<b>Abstract</b>	<b>ii</b>
<b>Acknowledgements</b>	<b>iv</b>
<b>List of Figures</b>	<b>vi</b>
<b>List of Tables</b>	<b>viii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Introduction . . . . .	1
1.2 Product Design and Developement . . . . .	1
1.3 Industrial Design . . . . .	3
1.4 Solutions . . . . .	5
1.4.1 LMS AMESim . . . . .	10
<b>2 Simulation</b>	<b>11</b>
2.1 Case Study . . . . .	11
2.1.1 Computer Aided Design Drawings . . . . .	12
2.2 AMESim . . . . .	18
2.3 Opening-closing mechanism of the door of the oven . . . . .	19
<b>3 Optimization</b>	<b>37</b>
3.1 Experiment . . . . .	37
3.2 Optimization and parameterization of the case study . . . . .	41
3.2.1 Export . . . . .	43
3.3 A Model of the User as a Mechanical Load . . . . .	50
3.3.1 Model . . . . .	50
<b>4 Conclusion</b>	<b>58</b>
<b>A References</b>	<b>60</b>

# List of Figures

1.1	An iPod, an industrially designed product. . . . .	4
1.2	Typical design process from Lawson [5]. . . . .	5
1.3	An example of 2D drawing . . . . .	6
1.4	Finite element analysis of a component belonging to TON die casting . . . . .	7
1.5	A scale model of an airplane in a wind tunnel for testing. . . . .	8
1.6	Complete computer simulation of a bacterium . . . . .	10
2.1	LUCE SX 1046LPX S . . . . .	11
2.2	Features . . . . .	12
2.3	Technical details . . . . .	12
2.4	Housing . . . . .	13
2.5	Shells to be placed on the back of the oven . . . . .	14
2.6	Side panels . . . . .	15
2.7	Gasket . . . . .	15
2.8	Door compartments . . . . .	16
2.9	Door frame . . . . .	17
2.10	Diplomat hinge . . . . .	17
2.11	The location of hinge . . . . .	18
2.12	AMESim Simulink lab . . . . .	19
2.13	Opening-closing mechanism of the door of the oven . . . . .	20
2.14	Main body block diagram . . . . .	21
2.15	Port positions in parameter mode . . . . .	21
2.16	Real hinge . . . . .	21
2.17	Force directions . . . . .	22
2.18	First part of block diagrams . . . . .	23
2.19	Second part of block diagrams . . . . .	25
2.20	Third part of block diagrams . . . . .	26
2.21	Fourth part of block diagrams . . . . .	27
2.22	Set parameters for cam and follower mechanism . . . . .	27
2.23	Cam profile shown with light blue line . . . . .	28
2.24	Cam profile in 360° . . . . .	28
2.25	Fifth part of block diagrams . . . . .	30
2.26	Sixth section Block diagrams . . . . .	31
2.27	AMESim parameter . . . . .	31
2.28	Run Parameters . . . . .	32
2.29	Start a simulation . . . . .	32
2.30	Assembly mode . . . . .	33
2.31	Assembly mode . . . . .	33

2.32 Animation of the opening-closing mechanism of the door of the oven with Large opening . . . . .	33
2.33 Stay-rod variable list . . . . .	34
2.34 Graph for position, velocity and acceleration of the main body . . . . .	34
2.35 Animation of the opening-closing mechanism of the door of the oven with small opening . . . . .	35
2.36 Graph for position, velocity and acceleration of the main body with snap back effect . . . . .	36
3.1 An overview of the sensors installed on the oven . . . . .	38
3.2 Load sensor . . . . .	38
3.3 PCB Pieszotronics accelerometer . . . . .	39
3.4 Single Axis Watson VSG . . . . .	39
3.5 Initial and final position of the door of the oven . . . . .	40
3.6 Experiment data . . . . .	40
3.7 Curve fitting of load data vs. time . . . . .	41
3.8 Curve fitting of acceleration data vs. time . . . . .	41
3.9 Curve fitting of velocity data vs. time . . . . .	42
3.10 New load function $f(x) = 356.8 * \exp(-((x - 3.691)/0.07581)^2)$ . . . . .	42
3.11 New load function $f(x) = 356.8 * \exp(-((x - 3.691)/0.07581)^2)$ . . . . .	42
3.12 New load function $f(x) = y * \exp(-((x - 3.777)/0.1385)^2) + z * \exp(-((x - 3.68)/0.07037)^2)$ . . . . .	43
3.13 Export setup . . . . .	44
3.14 Export setup . . . . .	45
3.15 Input parameters . . . . .	45
3.16 Simple output parameters . . . . .	46
3.17 Compound output parameters . . . . .	47
3.18 Simple output parameters . . . . .	47
3.19 Design exploration dialogue box . . . . .	47
3.20 Genetic Algorithm . . . . .	48
3.21 First optimization based on the Genetic Algorithm . . . . .	48
3.22 Solution progress dialogue box . . . . .	49
3.23 Optimized velocity of the model vs. Real velocity obtained by measurement . . . . .	50
3.24 Eight-element model of the users impedance, modeling the passive mechanics for frequencies >20 Hz. . . . .	51
3.25 Global parameter setup dialog box . . . . .	53
3.26 Hand user elements implemented in AMESim . . . . .	53
3.27 Hand user elements implemented in main model . . . . .	55
3.28 The mechanical imedance function in parameter mode . . . . .	56
3.29 Mean values of the mechanical impedance model according to figure 3.24 for different grasping siutations . . . . .	56
3.30 Impedance measurement settings for different grasps [13] . . . . .	56
3.31 The plot of the force exchanged between finger-tip, bones and muscles . . . . .	57



# List of Tables

3.1	Best solution found via the criterion minimizing “final value of the integral of squared difference between speed of the modeled system and that of the real experiment” . . . . .	49
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*All my love to my mom, for finding me the light, whenever it was  
far away...*

# Chapter 1

## Introduction

### 1.1 Introduction

In 21st century, the competitive market pushes the companies to launch their products faster and cheaper. So in order to decrease the time of product design process, new methodologies suggesting “*Virtual prototyping method*” is introduced in the first chapter. The advantages and effects of this method are explained briefly in the following.

In the second chapter the case study which is an oven distributed by Indesit Company is dismantled part by part. The software LMS AMESim is introduced to simulate the opening-closing mechanism of the door of the oven.

In the third chapter the optimization is clarified step by step thanks to the software AMESim. Finally modeling of the user as a mechanical load is carried out.

### 1.2 Product Design and Development

The definition of the term *product* includes a range of simple objects starting from a book or a bottle of water to intricate objects like home appliances or even electronic circuit boards. The word *Design* means a set of plans and drawings showing how a product is to be made in sense of geometry, material or styling and generally it deals with the *function* and the *look* of the product. Design could be simple or complex such as fitting the chain of a bicycle at the proper place or building IC chips respectively. Tong and Sriram [1] describe design as “a process that constructs a description of an artifact, process, or instrument that satisfies a (possibly informal) functional specification, meets certain performance criteria and resource limitations, is realizable, and satisfies criteria such as simplicity, testability, manufacturability, and reusability”.

*Development* deals with product marketing meaning identifying the market opportunities and trying to build and represent what is demanded to be sold out to customers. Companies work with clients every time and it is important that they can find the right product to begin with. Because if they do not start with a suitable product, it will be harder to revise it further at the succeeding industrial design stages.

Now a question arises. What is a right product? Firstly, it has to satisfy the correspondent demand sent from market. Actually those demands need to be straight forward meaning simple and clear. So the *product design process* is the transformation of an idea, a demand from the market place or a need of a purchaser to the design of a product that satisfies that need. The stages are explained here briefly to make it easier to understand. Besides, additional terms in marketing are introduced here shortly.

### **Fuzzy Front End**

The term *Fuzzy front end* or what is abbreviated as FFE simply refers to the stage where designers get together in order to figure out what a product should be, what a product should do or even what a customer experience should be. At this level, they do research activities like creating “*focus groups*” or conducting “*voice of the customer*” interviews where they learn how to define a product. In other words, the organizations decide if it is worth to invest resources on an idea at further development stages or not. This term became famous by Smith and Reinertsen [2] in 1991 and is counted as one of the early stages of product design process and roughly covers the period from generating an idea to its satisfactory for development or elimination. The effort made in this stage has a good effect on the whole innovation process.

### **Voice of the customer and pain points**

Voice of the customer or simply VOC is tightly associated with marketing and identifying the lack of comfortability of any item, like when a customer declares that a particular product does not fill in his/her needs in a second way. Thus when we are looking for pain points, in fact we are seeking an opportunity to create a solution. In other words it can be considered as an interaction between the customers and the marketers. The marketers listen to positive and especially negative opinions of their customers via many channels such as groups, communities, blogs and etc. Nowadays companies, brands and campaigns overcome the lack of responding towards their purchasers. They compensate it with quickness in answering and getting feedback from their products end-user which could drive the companies forward like a motor in a system.

## VOC trends

The trends come through a variety of different industrial groups where different colors, different materials and different textures are all combined to create interest from the customer and of a particular buying pattern. VOC trend is approved by the industry leaders and project managers as a next great business battlefield. According to Aberdeen group [3] associated with Harte-Hanks Inc. in USA, the customers would like to see an increased attention on the product services and support from their companies despite a fast decision for resolving defects in the products.

## VOC relation to Form and Fuction

Nowadays, companies should take into account the customers ideas and opinions and link it with all the decisions made in the whole systems-engineering field. The voice of the customer must be used in parallel in the development level.

Companies always try to make a balance with form and function, depending on the company itself on which factor spends more time but generally the inputs for *function* is gained from voice of the customer particularly pain points and for *form* designers should care about the leading trends that influence how a product looks acceptable.

## 1.3 Industrial Design

The role of industrial design or ID is getting broader and broader everyday where sometimes intersects with marketing and engineering. We take marketing as an input, like who the customer is, what the customer wants, what comes back from customer studies, where the market opportunities are and etc. Instead industrial designers face with designing products. ID is an original role and certainly is one branch of design that has much in common with architecture and with many other fields such as engineering.

Industrial designers take input from the engineering and marketing and then doing research in depth to explore the customer interests. They start creating a solution around the function and form and merry those two in a way that not only aesthetic but also an experience that is considered as a product solution.

Product solution concept starts off with rough sketches, moving through concepts rendering, typically through industrial design process, they go back to the customer that the sketches and ideas and renderings make sense with the customer.

Once the renderings are confirmed then we move into the 3D *computer aided design* drawing simply called CAD drawings where we actually have a delivery board there.



FIGURE 1.1: An iPod, an industrially designed product.

Up to this stage, there has been no interacting in an increased level with engineering department to make sure that the design, the choice of materials and the geometries make sense except through the 3D CAD design stage that the design engineering have the most communication where the industrial designers make sure that the exterior function make sense while the engineering have negotiation with industrial designer about the process to get assured that they optimize the whole process in order to make a successful product.

According to industrial designers, a product has to include inherently two main characteristics including a great looking product and great functioning. Primarily accomplished their task then it turns into defending that aesthetic and keep it up through the rest of the ramp up to manufacturing. This is controlled by checking and making sure that their changes into the model are due to the manufacturing and it is done in a way that maintains the original design that was created through the core of industrial design process.

Products are designed to make an awesome first impression on the customers so it is important to take packaging and branding into account in order to create a lasting emotional impact to the customer.

**typical design strategy** As explained before the design process is based on an analysis following design strategies and processes. This process is about how the industrial designers face with the problems. Asimov [4] demonstrated it as a sequence of analysis, synthesis and evaluation inside each stage generalized to the whole process Figure 1.2. There is a list of typical strategies in the following:

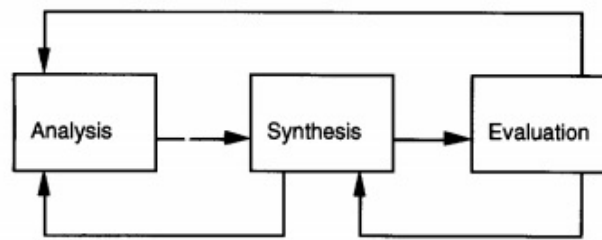


FIGURE 1.2: Typical design process from Lawson [5]

1. Feasibility Study
2. Preliminary Design
3. Detailed Design
4. Planning the production process
5. Planning for distribution
6. Planning for consumption
7. Planning for the retirement of the products

### Typical design process

1. Analysis
2. Synthesis
3. Evaluation - extended to
4. Revision
5. Implementation

## 1.4 Solutions

When somebody has a product to process we typically start out with some kind of 3D or 2D representation of the geometry either from a computer aided design namely CAD or sometimes we can start with 2D drawings namely sketches fig. 1.3 and we start building 3D representation in CAD. In fact CAD profits from the advantage that all the drawings are in form of standard sheets and are used in every communications. Thus CAD is 3D

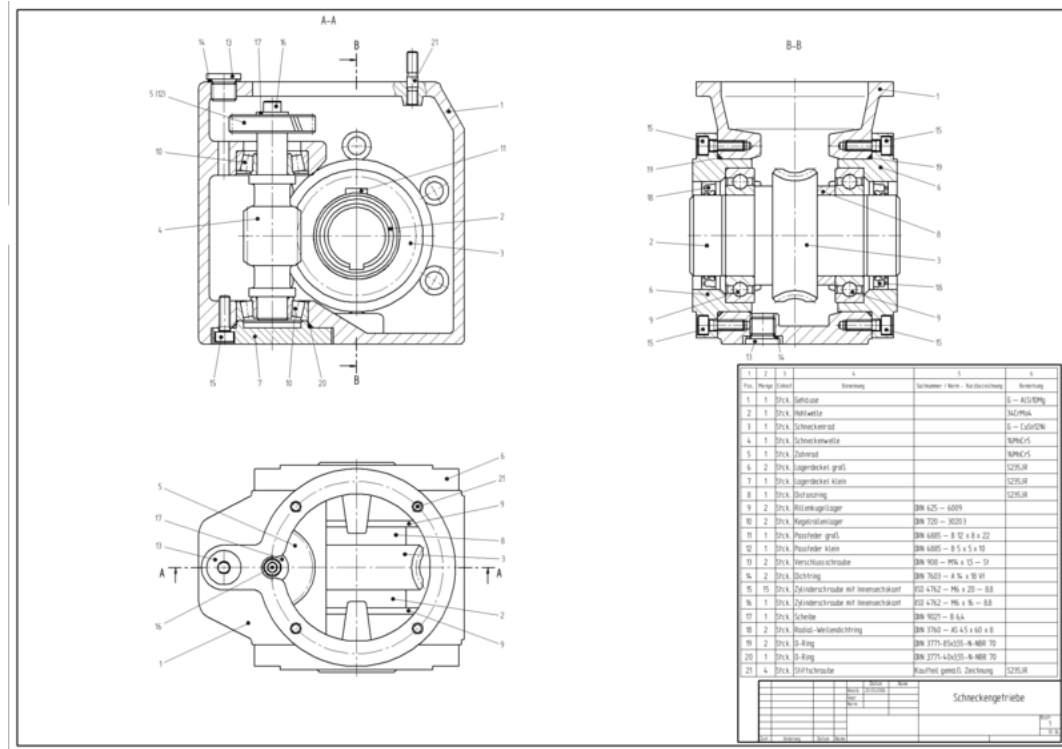


FIGURE 1.3: An example of 2D drawing

computer aided design system that allows up to shape or to form of a product. We can also check fitting a product during assembly to see how everything is located and check the tolerances. Also CAD is used to re-design and optimize a product.

### Finite Element Analysis

The next step in the process of finding a solution is the simulation portion. That is usually done in *Finite Element Analysis* or what is known as FEA software. This is the stage where we take a continuous model either developed in a CAD system or in the finite element software itself. The solid model or 2d representation (the sketch) are discretized by using meshing in the finite element software in order to be analyzed structurally, thermally, magnetically and etc in a single simulation using best-in-class software to predict and optimize the performance.

**Parametric Design** Quite often in simulation and design or optimization there are parameters that you might want to vary to see what the effects would be. It is called parametric design and it can be done in FEM software as well as the CAD software. It might be the height, thickness, width of a part or even diameter of a cylinder. It could be considered as a parameter so that we can analyze, simulate and optimize the design by considering all those aspects of design to get the best performance with the lowest cost.



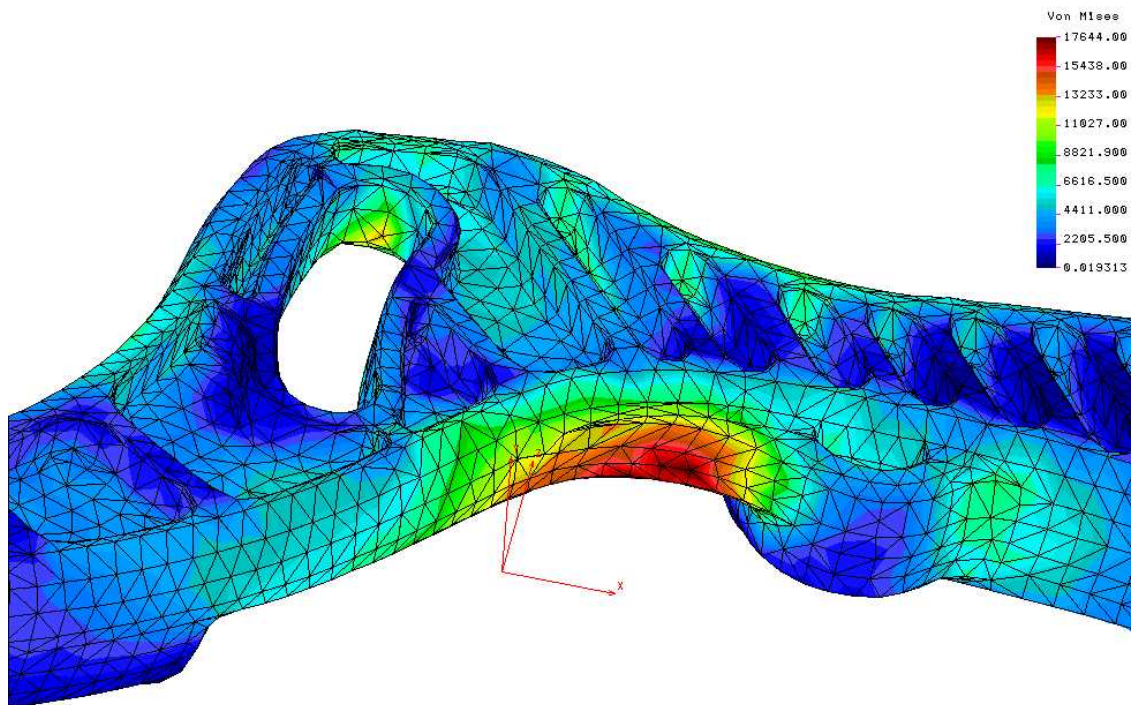


FIGURE 1.4: Finite element analysis of a component belonging to TON die casting

## Prototyping

*Prototyping* is defined as an early sample or a scaled model of an early product which is intended to build in order to test a concept and then be replicated in larger scale. Thus it can be re-designed if necessary before the product is manufactured commercially. From designers point of view prototyping is some design of the first order meaning just trying to come up with an idea and finally to come up with the part. It is like to be able to put everything together. They check whether the idea is going to work or not.

Furthermore after building the prototype we can take it to the laboratories and probe it for its functional, thermal or electrical properties. We can measure it to make sure everything is where it should be and of the right size and then it will fit or not if we put it in the final enclosure.

Pay attention that there is a limitation for building an appropriate prototype that it is just one instance of the hundreds of thousands of real product since each one of those prototypes might have a slight difference due to the manufacturing and component tolerances. So the question is, how many prototypes do you build? Everybody has to at least build one prototype. Across most people build two, three or even four. Thus what we face with is a large number of prototypes and that is the problem indeed because of



FIGURE 1.5: A scale model of an airplane in a wind tunnel for testing.

the high additional costs, depending on your type of products, a prototype could cost many thousands of euros depending upon the component that we are putting inside our model.

There is also a price to pay in terms of the schedule. Every time we build a prototype it is going to take two, three or four weeks that introduce additional delay into your development cycle. So what causes these iterations of the prototype? In fact it can come from many areas including electrical problems such as signal and power integrity or EMC (Electromagnetic compatibility) for printed circuit boards. It could be caused by a functional problem such as hooking up with the scheme or plan incorrectly. It could be a manufacturing, reliability or a fit issue. So imagine that your prototype is an assembly of different parts and it is going to be implemented in an enclosure but it does not fit properly. It might clash with some other parts. So what can we do to eliminate all these iterations of making prototypes?

### **Virtual Prototyping**

A prototype is a digital model that contains links to all data, information and codified knowledge required to design, engineer and manufacture an artifact [6].

So a virtual prototype provides a lot more flexibility with respect to the physical ones. We can simply check the range of tolerances we spoke about earlier. In summary it is important that we have only one instance of model with physical prototype instead an infinite number of instances with virtual prototyping technology.

A real benefit of virtual prototyping is that the iterations are cheap. So we can very quickly make a change to the design and re-analyze it. With virtual prototyping there

could be multiple engineers all working on the same virtual prototype at the same time, performing different types of analysis. So virtual prototyping can eliminate real physical prototypes which resulting savings in development cycle time and cost.

It is considered as a business challenge since it is a trade-off between cost and performance and on the meanwhile it would be a challenge to the design engineers too. The designer is always in the trench and thinks of how to make a compromise between cost and performance meaning he has to think what is giving the most acceptable performance with the lowest cost.

It is all about how globally companies will turn into competitive business. If there is lower cost solution for a design and someone around the world is going to find it then it means that the solution will not be for the rest of the companies. In other words, a business firm prospers if it is the leader in finding the solution at earlier time.

The reports of Aberdeen group [7] shows that the companies or manufacturers that make an extensive use of the simulation at the early stage of the product design process, surpass other companies because of earlier release of their products either complex or simple ones, the cost of their product and the quality targets. So the best in class manufacturers hit the revenue with \$1.9 million lower costs for intricate products and \$21,000 for simple products

After the prototyping is done, an idea has been proved. Then the product is adapted to go into making a large number of same parts. Take note that the prototype has to get to the finished product to give the visual impact required to the customer and actually it is what a customer is looking for.

Nowadays companies are much more looking for what called a *Low-hanging fruit*. A low-hanging fruit is simply anything that adds to the product and makes it more attractive. It attracts more the customer, the end-user or the purchaser. Sometimes it is simple things that can draw the product to the next level in terms of sale or in terms of usability through their look for simple things.

### **Computer Simulation**

Computer simulation has become an inseparable part of mathematical modeling and also many other natural systems such as what astronomy, chemistry or physics. Basically a virtual model is created by some analytical tools and is run in order to have an estimation of the performance of the too complex systems. The model benefits from algorithms and equations that used to capture the behavior of the system being modeled while on the contrary a simulation has already got the assumed equations and by running the simulation the user has the advantage to check the results.

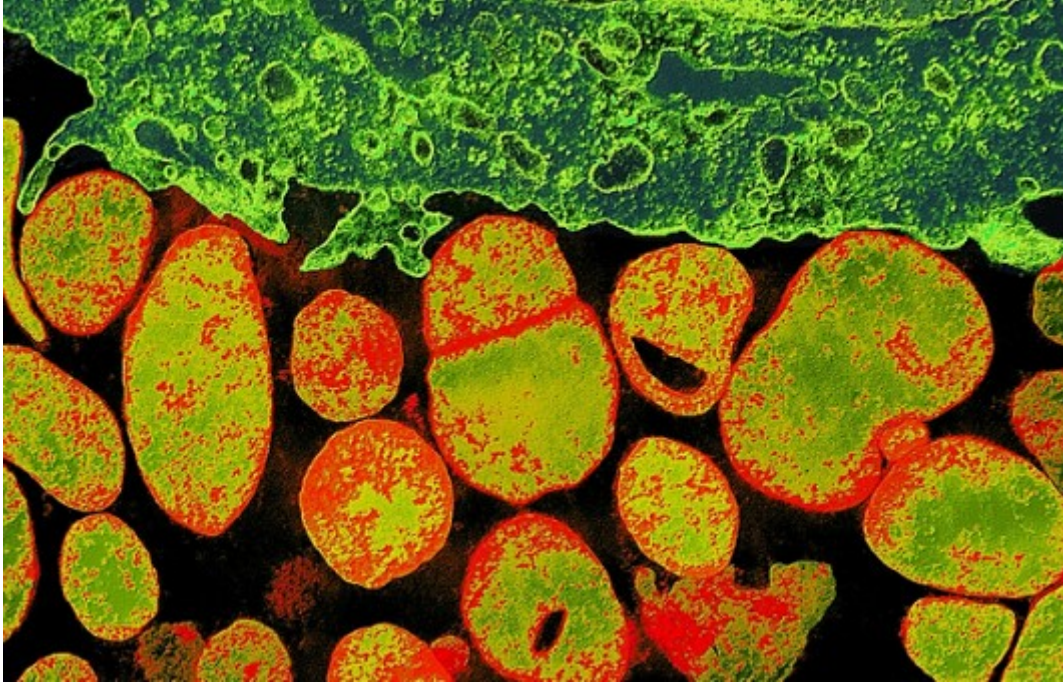


FIGURE 1.6: Complete computer simulation of a bacterium

As a matter of fact it helps us to obtain a more accurate prediction of the systems performance which respects the other side of the trade-off meaning the costs.

#### 1.4.1 LMS AMESim

AMESim is a commercial simulation software for the modeling and analysis of multi-domain systems. It is part of systems engineering domain and is located in the “*Mechatronic*” category.

The software package consists of tools used to model, analyze and predict the performance of mechatronics systems by using electrical and mechanical block diagrams which are of utmost importance. Models are described using nonlinear time-dependent analytical equations that represent the systems hydraulic, pneumatic, thermal, electric or mechanical behavior. This approach provides the capability to simulate the behavior of systems, hence it is used earlier in the system design cycle.

In the next chapter this software is used to simulate and optimize the mechanism of a hinge.

## Chapter 2

# Simulation

### 2.1 Case Study

The *Hotpoint Electric Heating Company* (generally known simply as *Hotpoint*) is a British brand of domestic appliances. The brand is currently fully owned by *Indesit*, an Italian multinational company based in Fabriano, Ancona province, Italy, a leading appliance manufacturer in Europe. In this project we concentrate on the oven of Indesit Company, namely LUCE SX 1046LPX S where its picture is shown in Fig 2.1.

An oven is an insulated container used to heat or bake food. There are different types of ovens like *Earth oven*, *Ceramic oven*, *Gas oven*, *Masonry oven* and *Microwave oven*. More recently oven has become slightly more high-tech in terms of cooking strategies and functions.

The features and technical data of the case study are shown here.



FIGURE 2.1: LUCE SX 1046LPX S

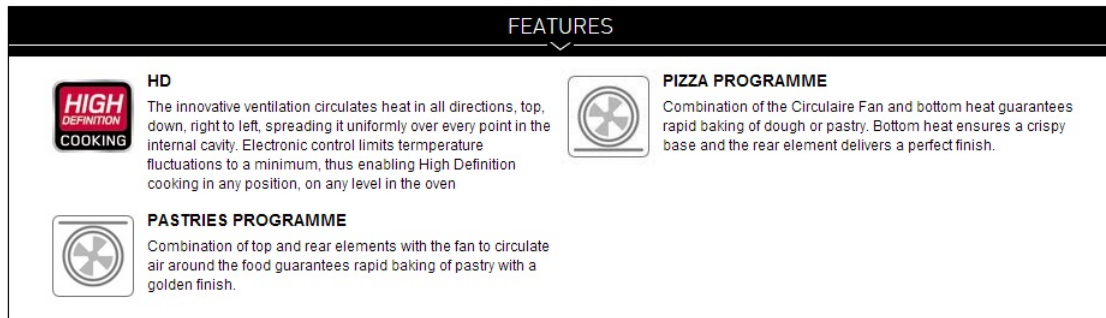


FIGURE 2.2: Features

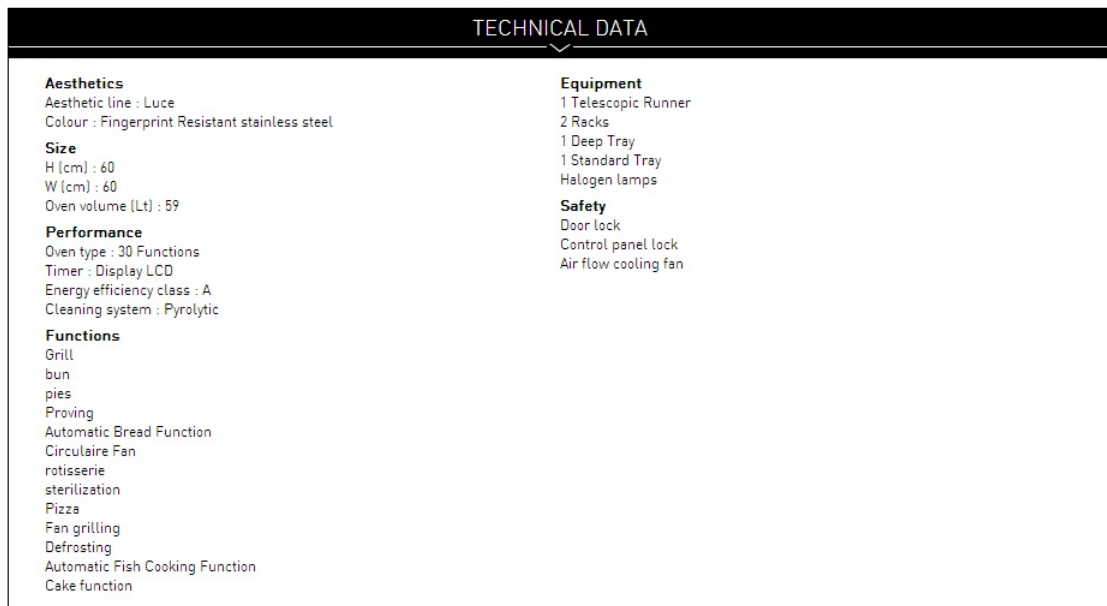


FIGURE 2.3: Technical details

We want to analyze the opening and closing mechanism of the door of the oven. Thus in the next section we are going to decompose the door in order to obtain a better understanding of the movement and associated compartments.

### 2.1.1 Computer Aided Design Drawings

Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design [8]. CAD software benefits the designer in sense of productivity, promote the quality of design since every operation could be used in the software and there is no need to draw an item on paper, enhance transferring through documentation, and to create a database for manufacturing [9]. A CAD file could get any suffix for print, machining, or other manufacturing operations. In mechanical design, it is also known as computer-aided drafting (CAD) which describes



FIGURE 2.4: Housing

the process of creating a technical drawing on a standard sheet with the use of computer software such as SolidWorks or CATIA.

CAD software for mechanical design uses either vector based graphics which is the use of the simplest geometrical objects such as lines, circles, curves, polygons, arcs, etc. to illustrate the objects of traditional drafting, or raster graphics demonstrating the overall appearance of designed objects involving more than just shapes. Like in the manual drafting of technical and engineering drawings, a CAD file has to convey information, such as materials, processes, dimensions, and tolerances, according to the specific application used.

As explained earlier, CAD could be used either to design 2D drawings such as sketches and 2 dimensional figures using basic geometrical properties like curves or to design solids in three dimensional (3D) spaces.

In our case study, The oven is created by assembling different parts like exterior *shells*, *side panels*, *door*, *gasket* and etc. which is created separately, then assembled to form the final product. Each part like door may include different sub-parts itself. Each part is modeled in the CAD software Solidworks. Generally the parts are divided into two categories. The ones used in the base and those in the door. The drawings of the parts are represented in here to have a better evaluation of the model.

### 1- Base Parts

First, the *housing* also known as coving is a piece of material with different shapes used to cover transitions between surfaces from solid milled plaster (Figure 2.4)

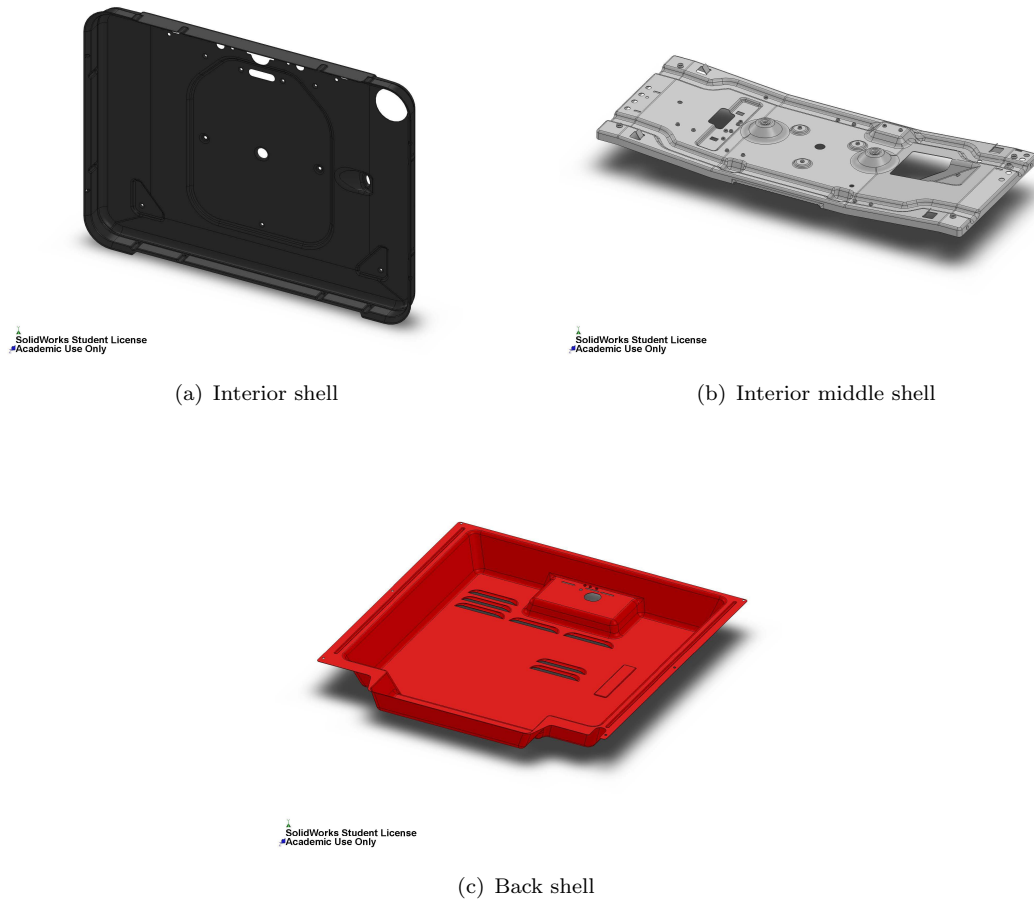


FIGURE 2.5: Shells to be placed on the back of the oven

Besides, there are Shells molded to fix the housing to the wall from behind for modern classic looking kitchens. The oven we deal with is considered as a *pyrolytic oven*. Using high temperatures of  $500^{\circ}\text{C}$ , a pyrolytic oven turns food residue and grime into ash which can then be easily wiped clean using a damp cloth. No harsh chemicals or scrubbing required! For safety during use, the pyrolytic control securely locks the oven door, and only releases the lock once the temperature drops below  $300^{\circ}\text{C}$ . Because pyrolytic ovens are well insulated, efficiency is assured. Self-cleaning ovens usually have more insulation than standard ovens to reduce the possibility of fire. The insulation also reduces the amount of energy needed for normal cooking. Furthermore, these ovens have walls coated with heat and acid-resistant porcelain enamel which is a material made by fusing powdered glass to a substrate by firing.

This is a *Convection oven* known either as a fan-assisted oven or a fan oven that has fans to circulate air around food on the contrary of *Conventional oven* where no fan is used inside the oven. Then the heat generated inside the oven is transferred into the ambient by side sheets implemented on the left and right side of the housing.



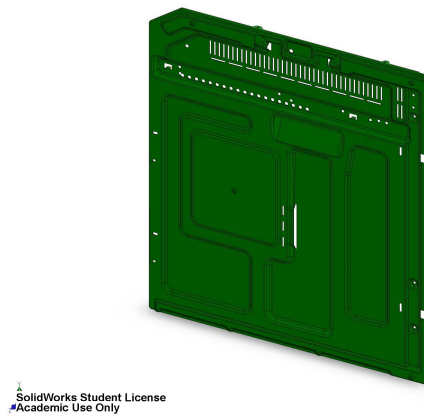


FIGURE 2.6: Side panels

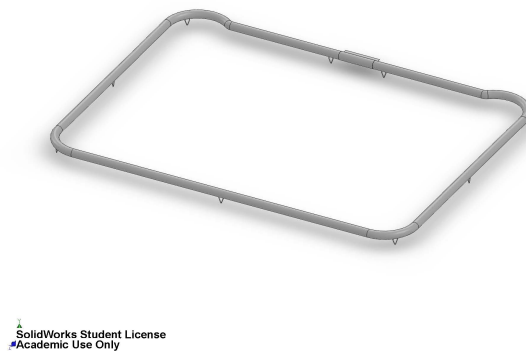


FIGURE 2.7: Gasket

A *Gasket* act as a mechanical sealing between two surfaces in order to prevent the leakage. Gaskets allow “less-than-perfect” mating surfaces on machine parts where they can fill irregularities. Gaskets are commonly produced by cutting from sheet materials such as silicons, fiber glass, copper and etc.

## 2- Rotating Parts

The rotating part includes the door which is composed by several portions like a steel sheet, pivots, rollers, condensation collector, handle and etc.

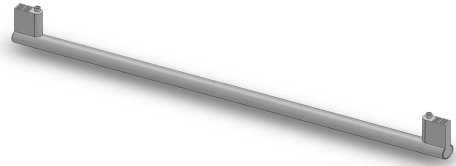
A hinge is a mechanical device that connects two solid objects, allowing them to rotate with a limited angle with respect to each other around a fixed rotation axis.

The opening and closing mechanism of the oven is based on the hinge parts which is explained in detail here. In the other words, the hinges aid the door of the oven to open



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(a) Condensation collector



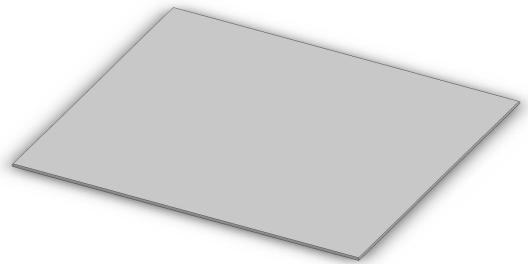
SolidWorks Student License  
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(b) Handle



SolidWorks Student License  
Academic Use Only

(c) Exterior Design



SolidWorks Student License  
Academic Use Only

(d) Steel Sheet



SolidWorks Student License  
Academic Use Only

(e) Facade Part 1



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(f) Facade Part 2

FIGURE 2.8: Door compartments

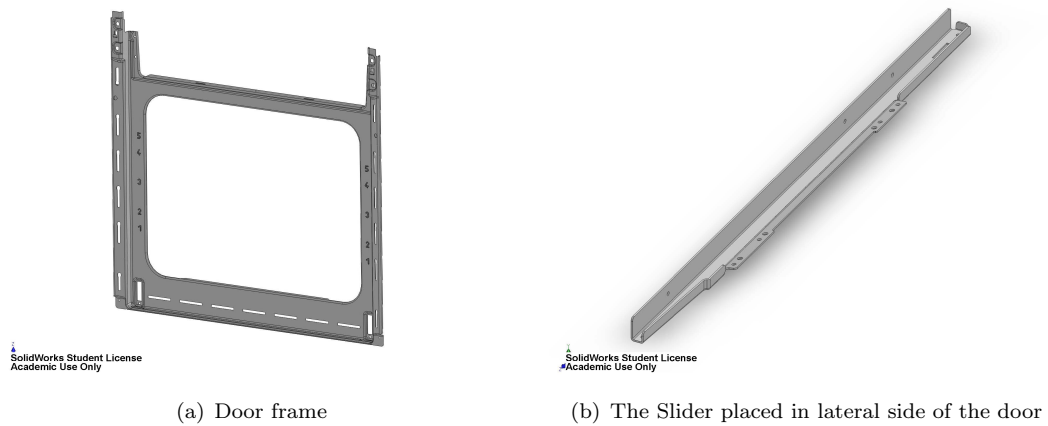


FIGURE 2.9: Door frame

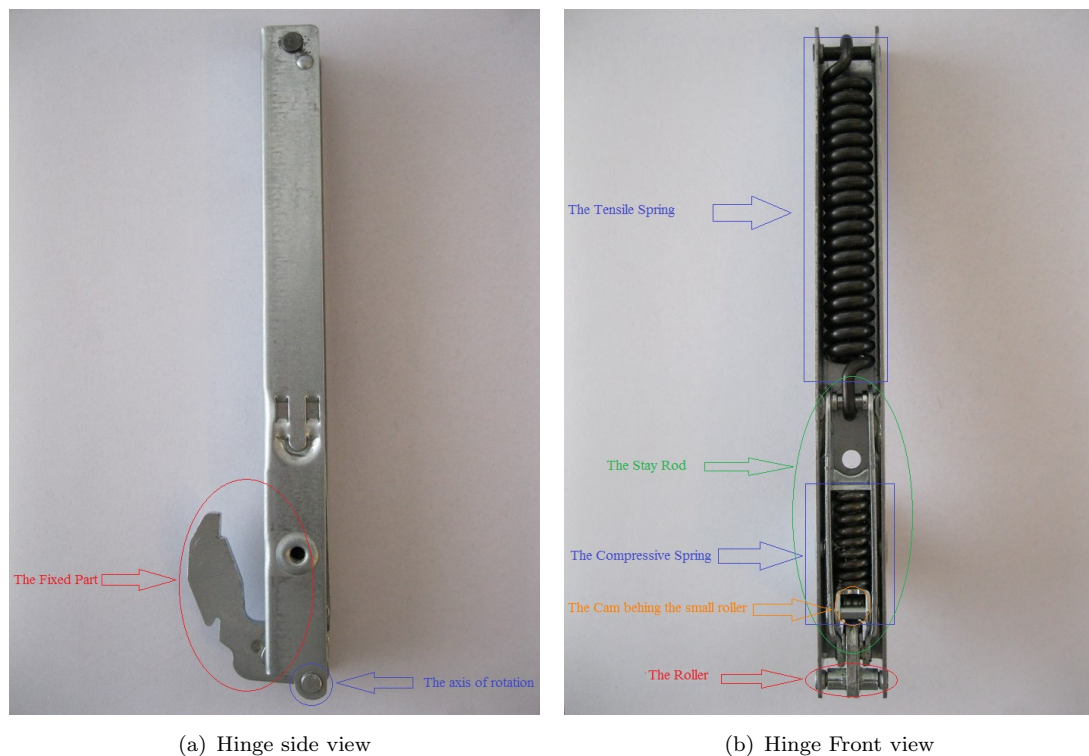


FIGURE 2.10: Diplomat hinge

and close. It includes many elements inside such as springs, a roller, a main stay rod and etc. Besides, there is a cam profile mechanism aids the door snap back to its initial position.

The hinge of this case study is called *Diplomat* that is used mainly in ovens and is one of the last generation of its type.

Of utmost importance is the hinge's location where is fixed inside the base at one end and is rotating at the other end.



FIGURE 2.11: The location of hinge

## 2.2 AMESim

In the first chapter the software LMS AMESim was introduced briefly. This software is used to model a mechanism composed of different parts. To create a simulation model for a system, a set of libraries is used, like signal library, mechanical library and etc. They contain pre-defined components each containing different mathematical equation for different physical domains. The elements in the system have to be connected and for this purpose each icon has ports, which have several inputs and outputs. Causality is imposed by connecting the inputs of one icon to the outputs of another icon (and vice-versa).

AMESim libraries are written in C language and it also supports Modelica which is a free source, object-oriented, equation based language to model complex physical systems containing, e.g., mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process-oriented subcomponents [10].

The modelling of a system is done in four steps:

1. *sketch mode*: in which the different components are linked.
2. *submodel mode*: in which the physical submodel associated to each component is chosen.

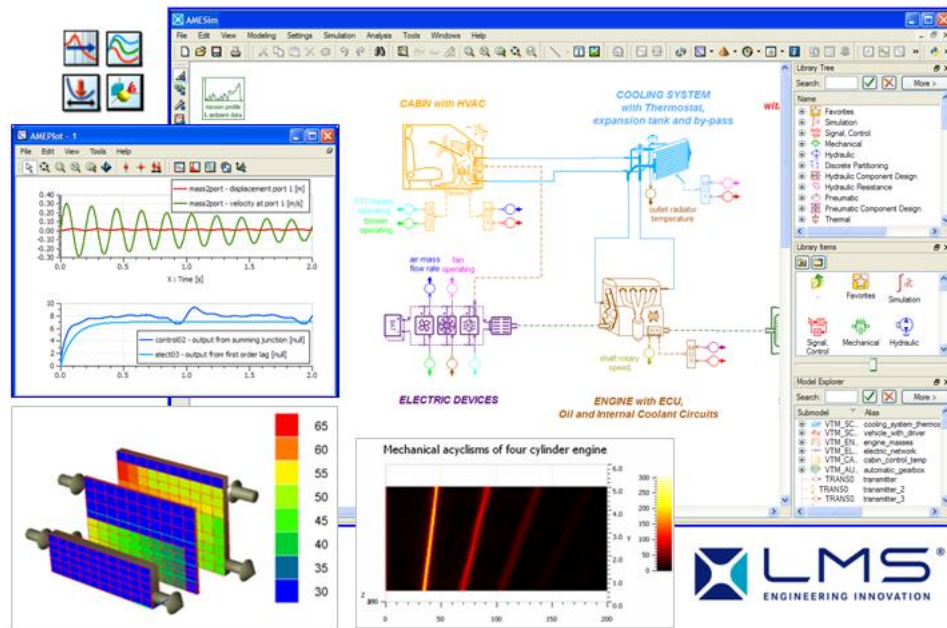


FIGURE 2.12: AMESim Simulink lab

3. *parameter mode*: in which the parameters for each submodel are set.
4. *run mode*: in which the simulation is started and results analyzed.

These four steps are discussed later. Between the submodel and parameter mode, the AMESim model is compiled. Under the Windows platform, LMS Imagine.Lab AMESim works with the free *Intel compiler*, which is provided with the software.

## 2.3 Opening-closing mechanism of the door of the oven

The opening-closing mechanism of the hinge is shown in fig.2.13. The whole mechanism is divided into six different parts. This separation is done in order to clarify the function of each sub-system.

### Main body, stay-rod

The main body has seven ports connecting different parts together. We use relative coordinates reference to make it easier to calculate the  $x$  and  $y$  coordinates of ports one to seven. The absolute angular position of the main body is equal to  $90^\circ$  in Cartesian coordinates. The weight of the hinge is considered as  $1\text{ kg}$  and the moment of inertia as  $0.01\text{ kg.m}^2$ .

The main body is demonstrated in fig.2.10.b and fig.2.14.

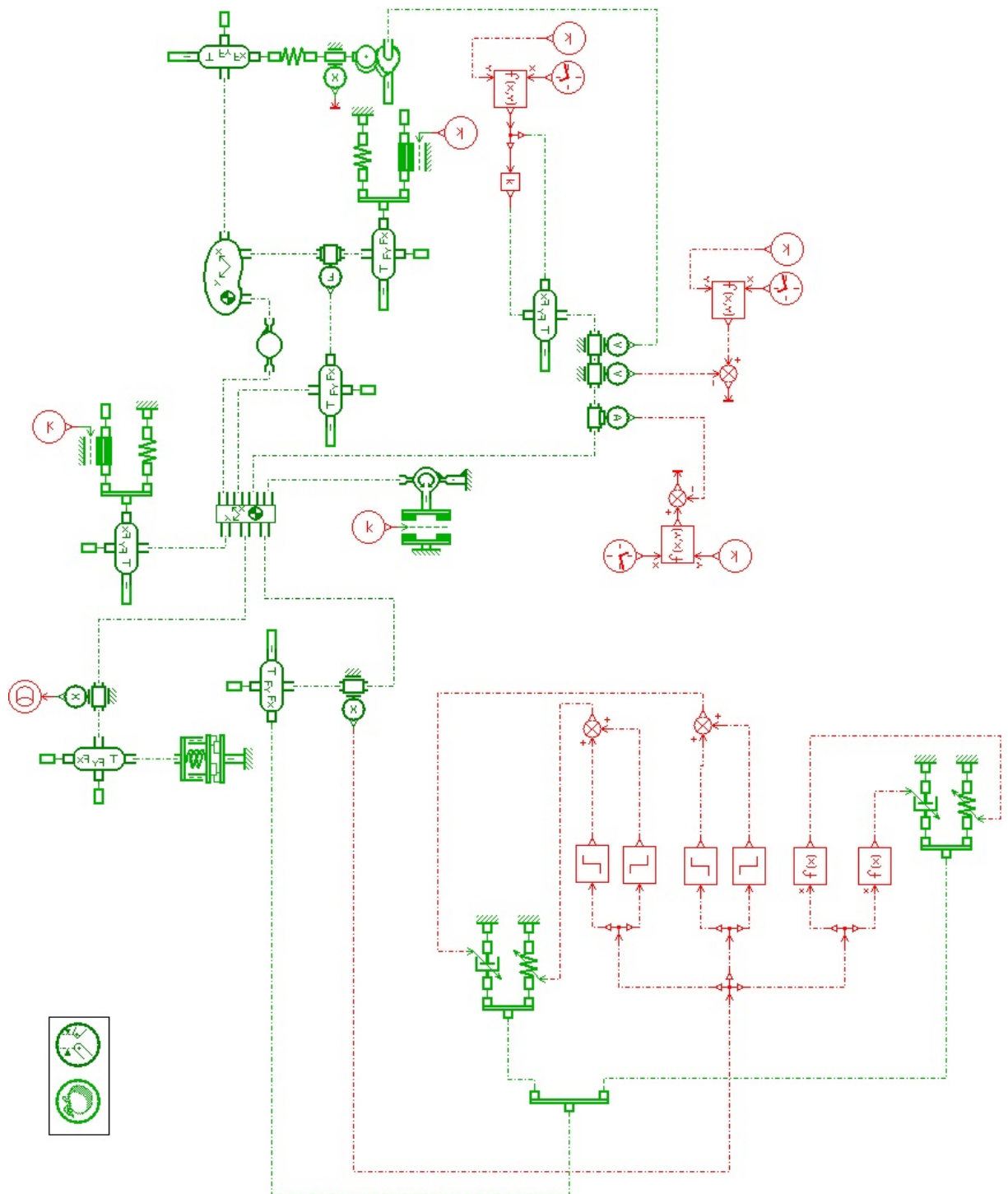


FIGURE 2.13: Opening-closing mechanism of the door of the oven

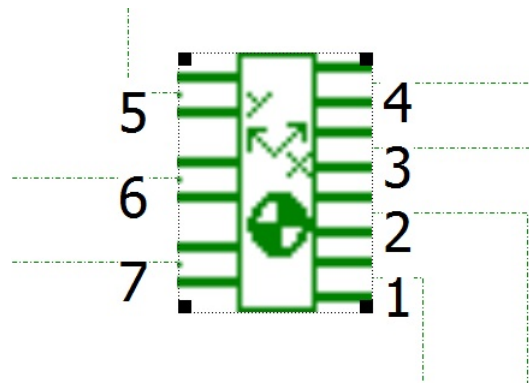


FIGURE 2.14: Main body block diagram

x position at port 1	0 mm
x position at port 2	80 mm
x position at port 3	50 mm
x position at port 4	15 mm
x position at port 5	80 mm
x position at port 6	0 mm
x position at port 7	0 mm
y position at port 1	0 mm
y position at port 2	0 mm
y position at port 3	0 mm
y position at port 4	3 mm
y position at port 5	0 mm
y position at port 6	0 mm
y position at port 7	0 mm

FIGURE 2.15: Port positions in parameter mode

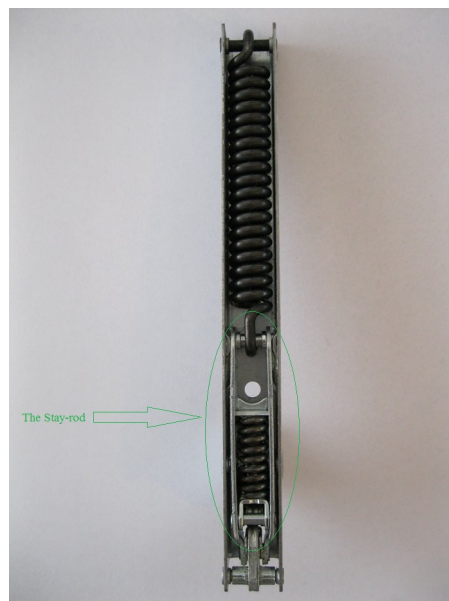


FIGURE 2.16: Real hinge

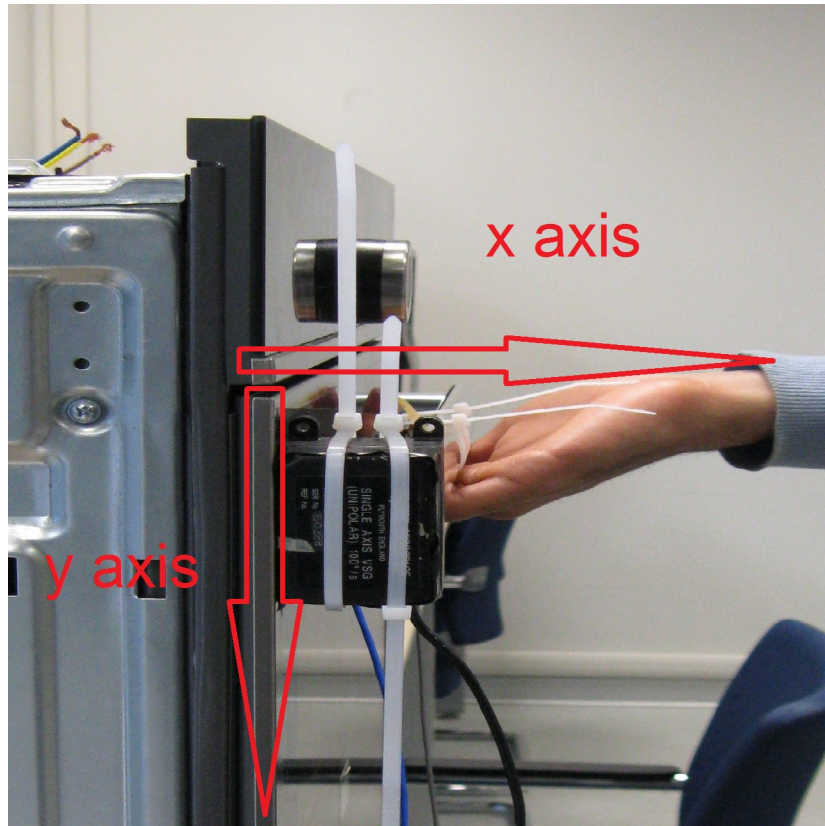


FIGURE 2.17: Force directions

The first part is about the input force. We apply an amount of force to the handle of the oven, as we hold and move it. The value of force starts from 0N and reaches a maximum (the summit) in a fraction of second, then suddenly falls back to the value 0N. So it is a parabolic function and similar to a Gaussians distribution function. The experiments in the next chapter confirm this hypothesis.

An amount of force 100 N is applied both in the  $x$  and  $y$  directions of the oven fig.2.17.

As explained before, the force can be considered as a function of Gaussians distribution form. The function of this type has the formula

$$f(x) = a_1 * \exp(-((x - b_1)/c_1)^2)$$

The parameter  $a$  is the maximum force applied to the handle and  $b$  is corresponding time of the peak.  $c$  is about how steep the parabola should be considered. So we choose  $a$  as 100N,  $b$  and  $c$  as 1.

As illustrated in fig.2.18, a constant gain is used to insert the value of maximum force, A clock whose input is the duration of the simulation and a function block diagram to



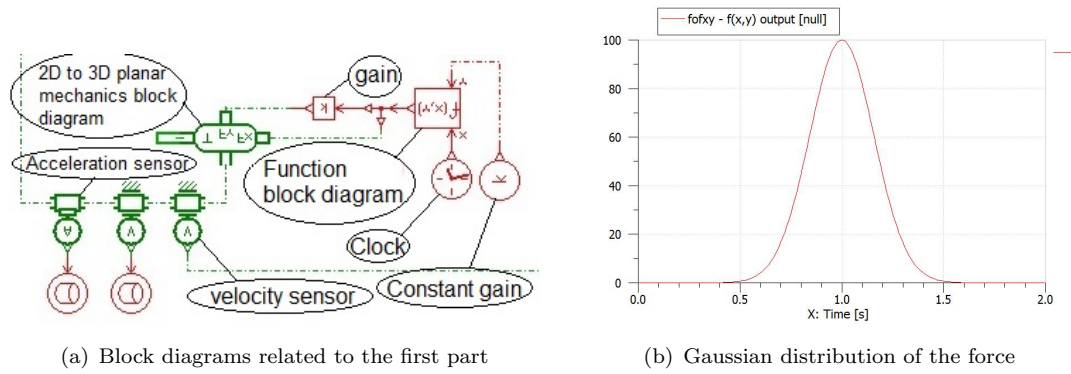


FIGURE 2.18: First part of block diagrams

insert the formula of Gaussian distribution function. Besides, there is gain to invert the direction of the force with respect to  $y$  axis.

A velocity sensor and an acceleration sensor are implemented to have an idea about the outcome velocity and acceleration where is used usefully in the next chapter for optimization of the mechanism.

Second part includes a “reference fixed body” and a “driver revolute pivot”. In addition there is a “rotary Coulomb friction” block diagram.

The reference fixed body is demonstrated in fig.2.10.a. It is located in absolute Cartesian coordinate  $(0, 0)$  and the corresponding absolute angular position  $0^\circ$ .

The driven revolute pair is used to connect the reference fixed body to the main body by a pivot. Apparently there exists a friction force since two metallic surfaces rotate with respect to each other. This friction is modeled with a rotary Coulomb friction which is considered as dry friction. Thus the force needed to move the mechanism must overcome the static friction and move the mechanism.

Coulomb described the friction force as:

$$F = F_c \cdot \text{sign}(v)$$

Where the friction force  $F_c$  (Coulomb friction force) is:

$$F_c = \mu \times F_n$$

Note that  $F_n$  is the normal force and  $F_c$  is tangential force.

The dynamic friction coefficient is set to 0.02 and the maximum Coulomb torque as 30 Nm. Rotary stick velocity threshold is set as default and the diameter on which the friction acts is 10 mm.

There is also a constant gain whose value is multiplied by the maximum Coulomb torque to calculate the “dynamic friction force”. The value of the constant gain must be a fraction lower than 1.

In third part, a tensile spring with its linear Coulomb friction is modeled. The spring tensile force is calculated manually according to the formula:

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n_a} \quad (2.1)$$

$$(2.2)$$

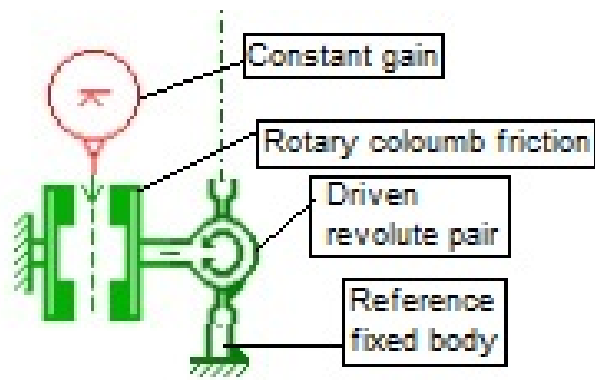
Where  $d$  is the spring diameter equal to 1 mm,  $G$  is shear modulus and 80 Gpa for steels,  $n_a$  is the number of active coils equal to 20 and  $D$  the nominal diameter is 15 mm. Then  $k$  would be around 5000 N/m and the amount of preload  $F_0$  is estimated at 300 N. The signal input is 3 meaning the friction force is obtained by the constant signal equal to 10 N. The maximum Coulomb friction force is equal to 5 N and the dynamic friction coefficient is dimensionless and equal to 0.3.

In reality the door of the oven does not rotate backwards when it is in closed position. In order to make the software understand this concept, two springs and dampers with very high stiffness are implemented behind the door. In fact, it is called a “wall because it restricts the rotation of the door of the oven when the angular position of the door is above 90°.

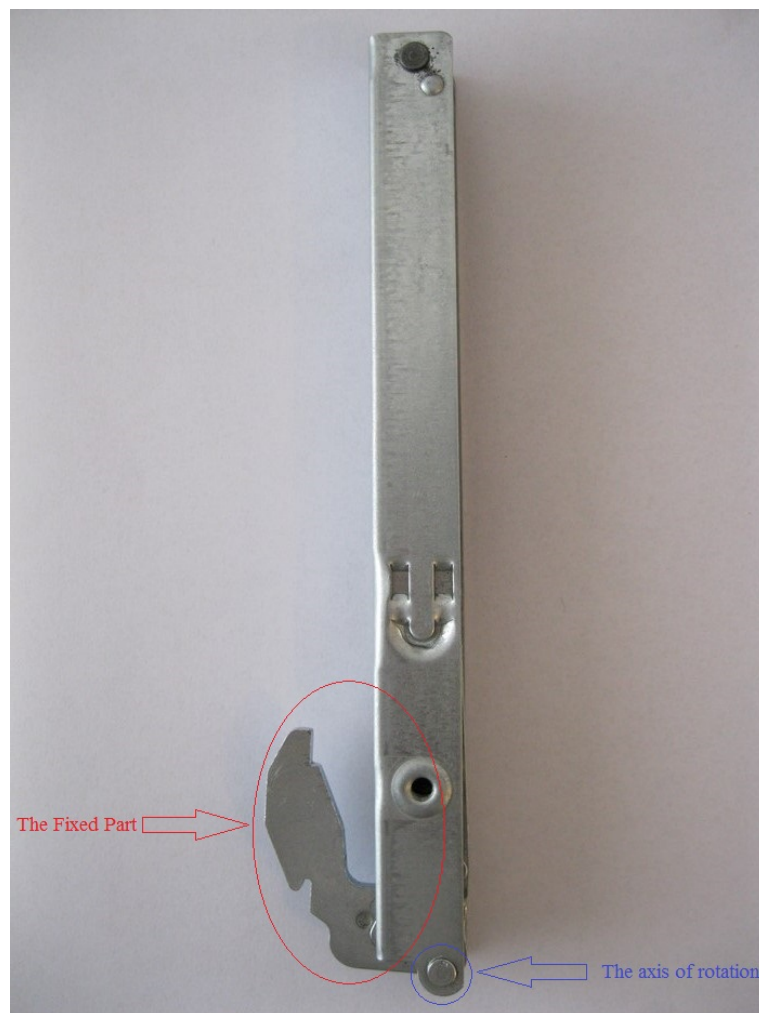
To do so we can put the stiffness as a function of the position, using a step block (red block section). The equations in the functions  $((-\tanh((x) * 100000) + 1)/2 * 1000000)$  are set in a way to deliver a high damping ratio if the condition is not satisfied.

In fifth part a three-port body is observed where in reality is the part where the follower pushes in order to compress the shorter spring. In parameter mode, we used a relative coordinate system with 90° initial absolute angular position. The  $x$  and  $y$  position of the initial absolute position is 15 mm and 3 mm respectively.

There is a compressive spring whose high stiffness is calculated according to the formula 2.1 and is evaluated around 10,000 N/m and spring force with both displacements zero is estimated at -500 N. The other important element in this section is the cam and follower mechanism. Pay attention that the cam is fixed here and does not move. In fact there is a special type of cam and follower mechanism. The profile of the cam is essential in order to be put as an input in parameter model fig.2.22. It is extracted from the CAD drawings and is shown in the figure 2.23.

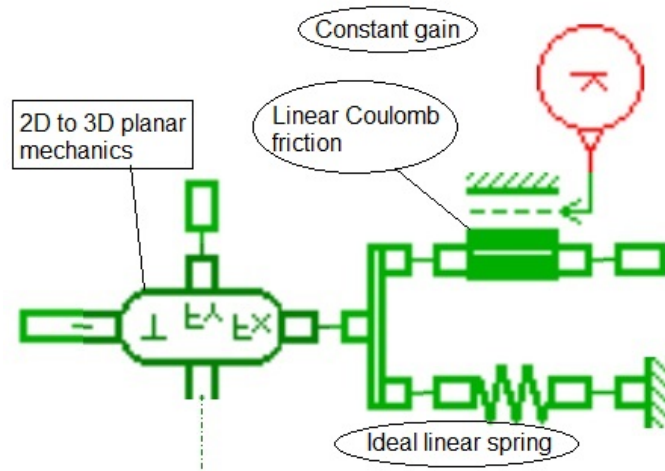


(a) Second part of block diagrams

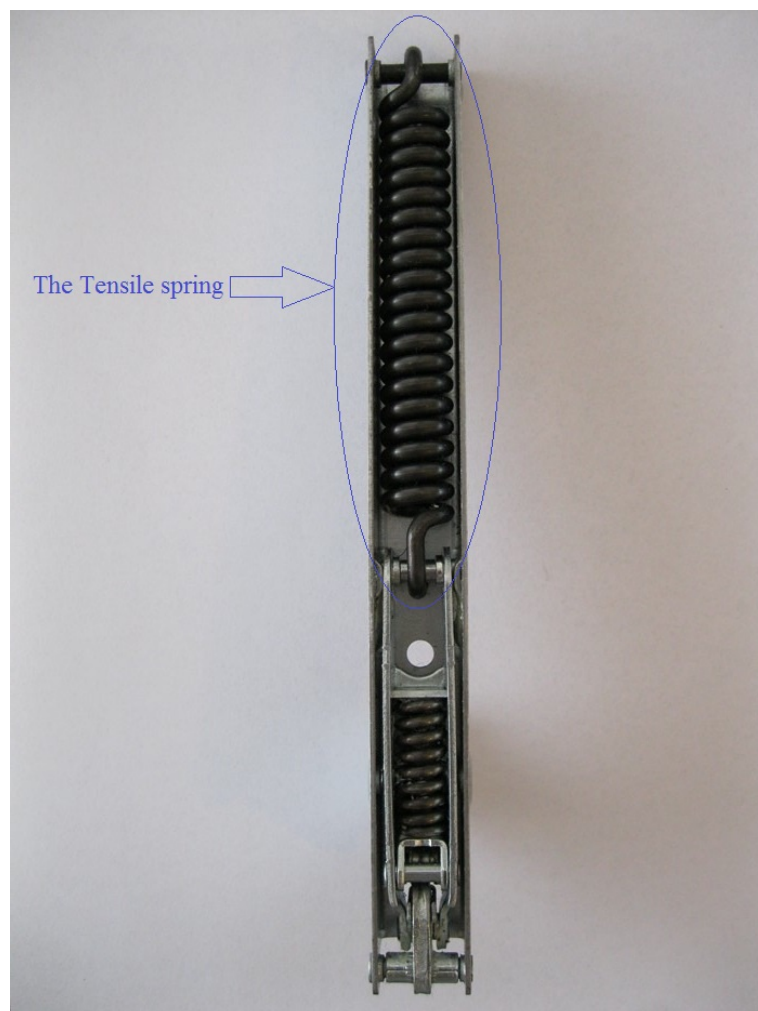


(b) Corresponding part in real hinge

FIGURE 2.19: Second part of block diagrams

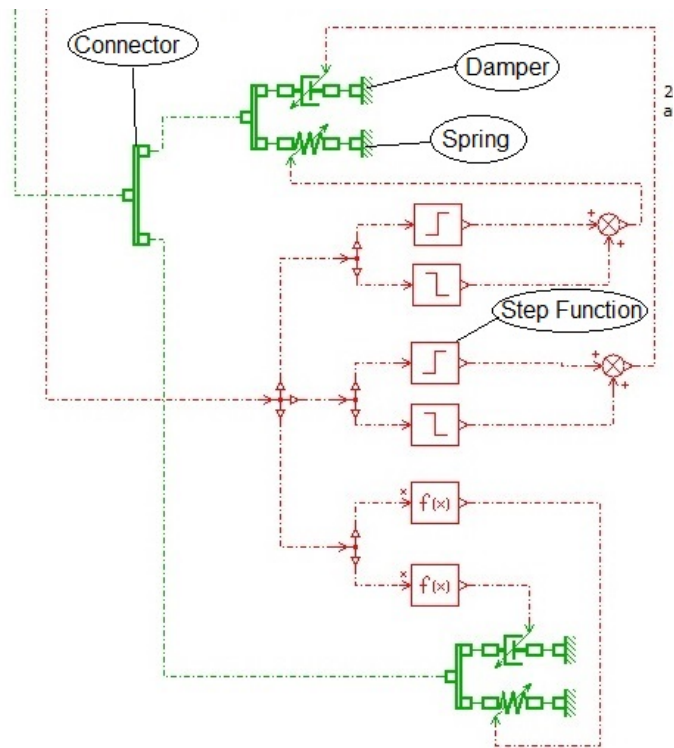


(a) Third part of block diagrams

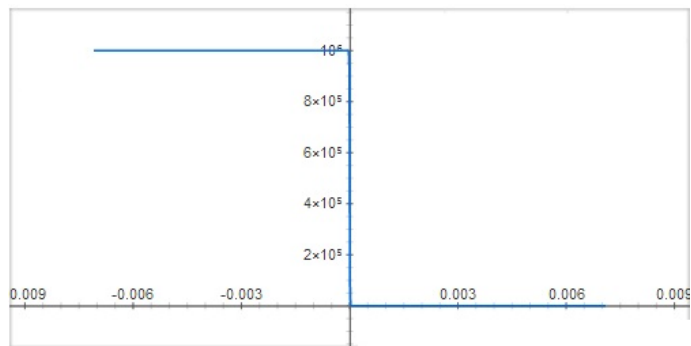


(b) Corresponding part in real hinge

FIGURE 2.20: Third part of block diagrams



(a) Fourth part of block diagrams



(b) The graph of tanh function

FIGURE 2.21: Fourth part of block diagrams

Title	Value	Unit
cam		
.. cam profile [mm] as a function of the reference angle [degree]	Cam Profile/CamProfileRevised_Curved.data	Cam and follower curve
discontinuity handling	active	
tolerance value for cam profile concavities	1e-06	null
angular displacement of the cam	29.6095	degree
follower		

FIGURE 2.22: Set parameters for cam and follower mechanism

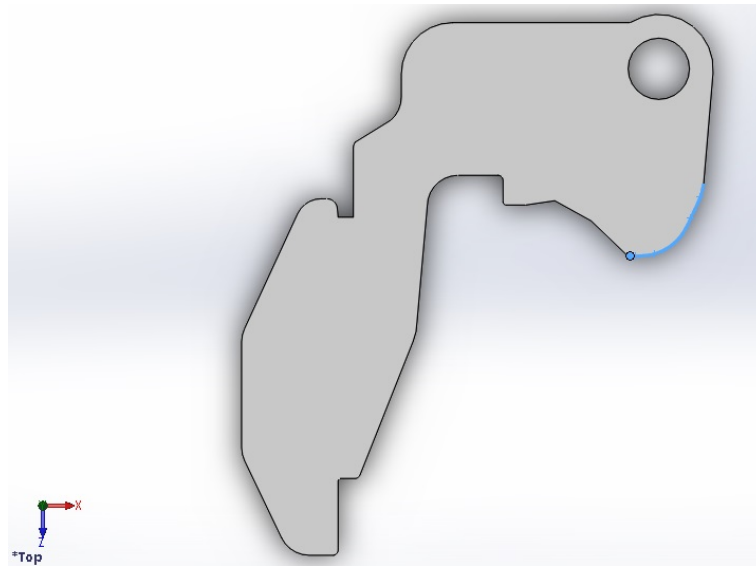


FIGURE 2.23: Cam profile shown with light blue line

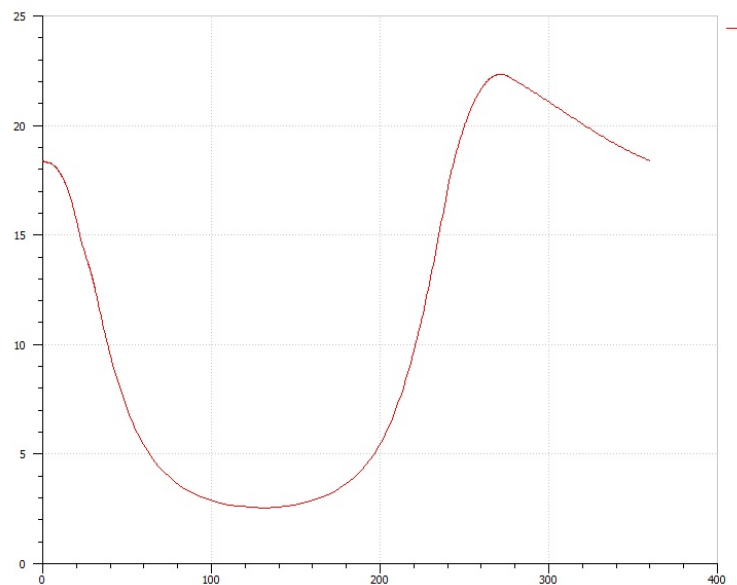


FIGURE 2.24: Cam profile in 360°

Then the characteristic equation of the cam profile is imported in the software MATLAB in order to change the data from an equation to the numerous points Cartesian coordinates. Because “AMESim table” accepts the cam profile in terms of its characteristic points and not characteristic equation. Then cam profile has to be converted into the scale of 360°. The angular displacement of the cam is put equal to 29.61° and the rest of the data is represented in the fig 2.24.

The  $\phi$  angle indicating the angular displacement of the cam is calculated according to the formula below that calculates the angle between two vector a and b.

$$\cos \theta = \frac{\bar{a} \cdot \bar{b}}{abs(a) \cdot abs(b)}$$

there are two points at both ends of the cam profile that creates two vectors with center of the cam. the positions of these two points are (11.19, 18.29) and (18.37, 11.19).

Furthermore there is a signal from velocity sensor in the main body where enters the angular velocity of the cam. There exists a force transferred from the *second body* into the *main body*, thus a *force sensor* is implemented to transfer the reaction of the spring to the main body (stay-rod).

In sixth part an *elastic end stop* is used so that the door of the oven is not allowed to rotate into an angle less than 0° or in a better word the door rotates maximum 90°. The required parameter of the elastic end stop is shown in fig.2.26.b.

In *Sketch mode* we designed the system with block diagrams, then in *Submodel mode* every component in the system must be associated with a mathematical model. This is a collection of mathematical equations and their implementation as a piece of computer code.

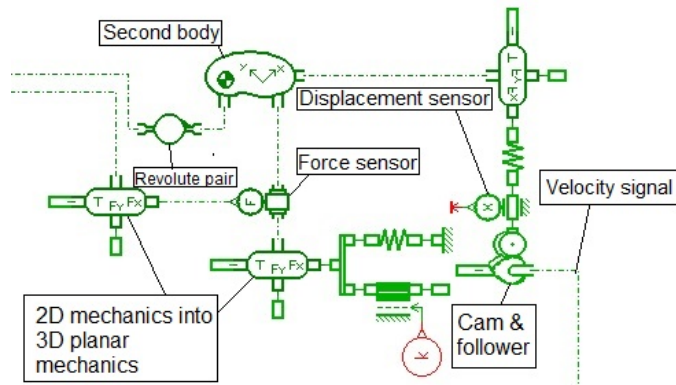
The AMESim nomenclature is to describe the mathematical model of a component of a system as a **submodel**. The term **model** is reserved for the mathematical model of the complete system. AMESim contains a large collection of submodels. As far as it is appropriate, the process of associating submodels with components is automated.

So, we click on the *submodel mode* button in the toolbar. With AMESim a single component may have more than one submodel that can be associated with it. For example for Dynamic friction model, we have many submodels and we chose the Coulomb dynamic friction model using tanh function. We simply use **Premier submodel** facility for the rest of the model.

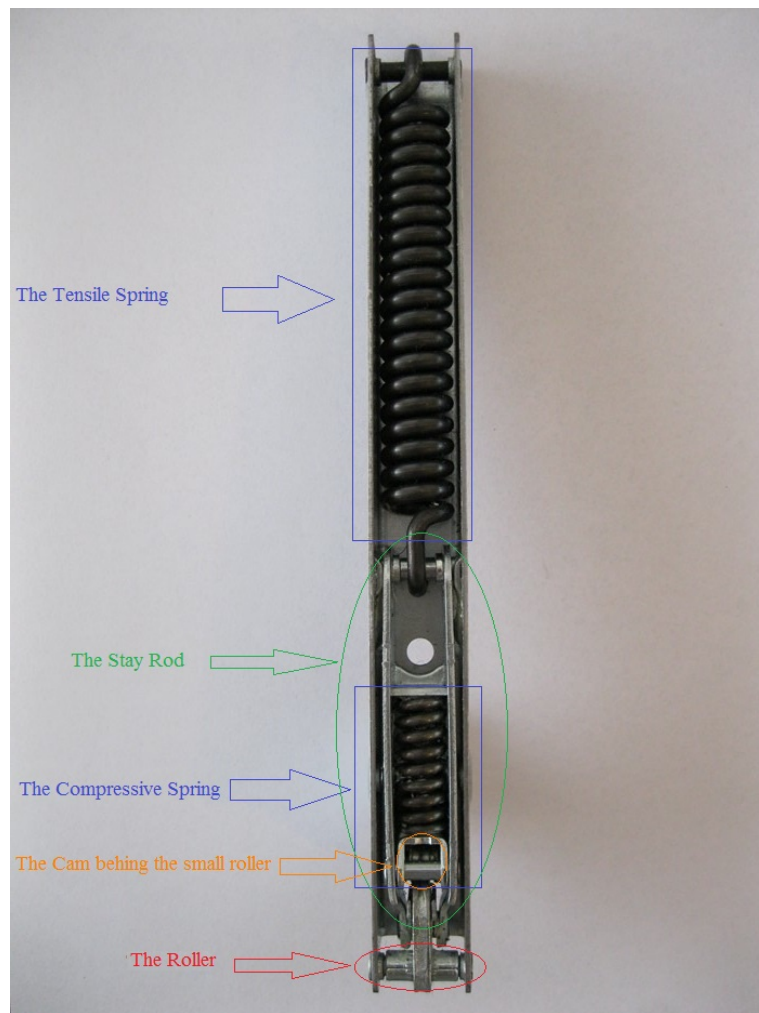
Next setp is setting *parameters*. AMESim performs various checks and creates an executable code for your system. The System Compilation window appears giving you some technical information about the equations it must solve to perform a simulation. We changed it as explained before.

For **Running a simulation** there are some steps. First, we should enter the *Simulation mode*, then we set the *Run parameters*. A dialog box appears (fig.2.28) that allows you to change the characteristics of a run like “start time” and “final time”. The dialog box is comprised of two tabs “General” and “Standard options”. The settings are set to default.

Then we click on “*Start a simulation*”, Then “run monitor dialog box” appears.



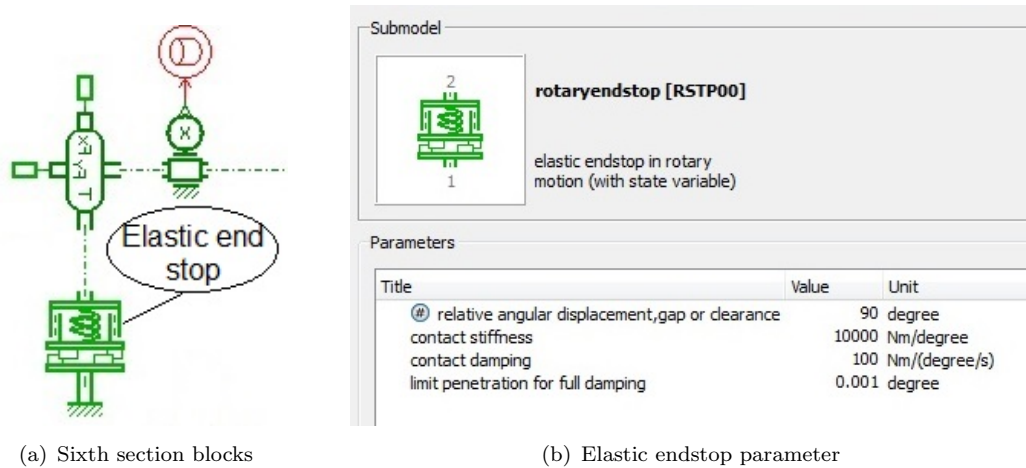
(a) Fifth part of block diagrams



(b) Corresponding part in real hinge

FIGURE 2.25: Fifth part of block diagrams





(a) Sixth section blocks

(b) Elastic endstop parameter

FIGURE 2.26: Sixth section Block diagrams

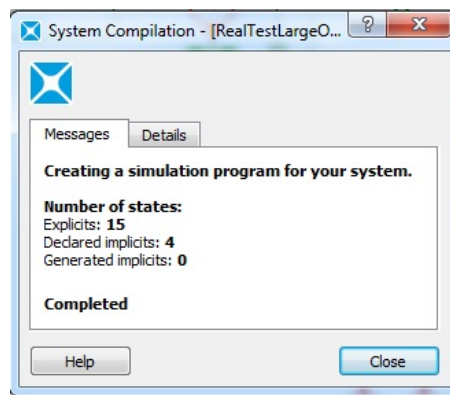


FIGURE 2.27: AMESim parameter

After running the simulation, it is the time to import the CAD models into AMESim, assembly mode. Thus we double click on the assembly icon on the left upper corner of the graphic window and this window appears fig.2.30.

Above the CAD model, a bar is shown (fig.2.31) where controls the animation part of the assembly according to the parameters selected for the models. With this bar, there is the possibility to play the animation of the oven with *Large opening* meaning without snapping back. The pictures are illustrated here fig.2.32.

The movement characteristics of the door including its position, velocity and acceleration are listed in the variable list after running the simulation.

The graph for absolute angular position, absolute angular velocity and absolute angular acceleration is plotted here.

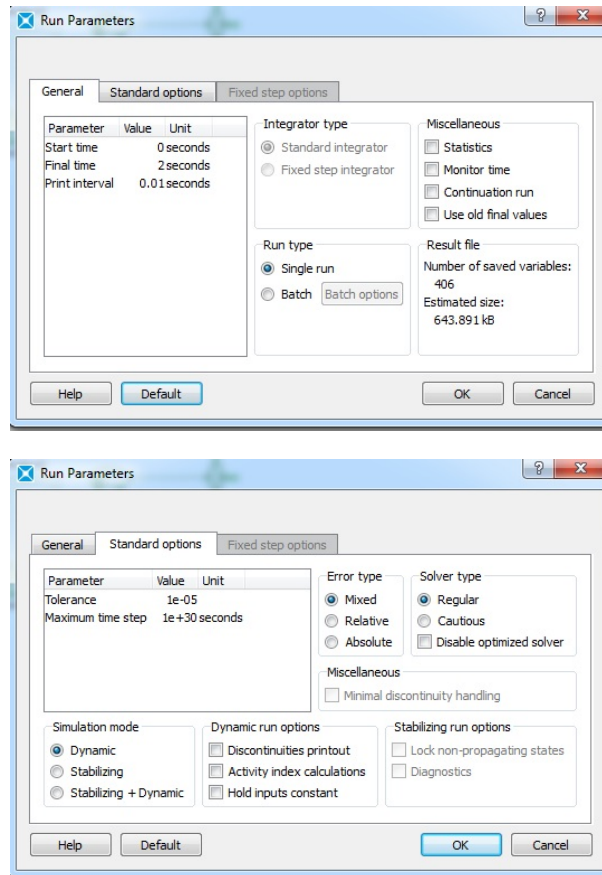


FIGURE 2.28: Run Parameters

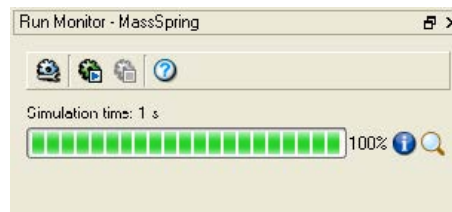


FIGURE 2.29: Start a simulation

As can be seen clearly in fig.2.34, the angular position is at  $90^\circ$  in its initial position, then step by step it decreases until it reaches a minimum point and after that a slight rise of the graph occurs where comes from the reaction of the springs. In absolute velocity graph the velocity is increasing until it reaches a maximum point (around  $-32 \text{ rev}/\text{min}$ ) then it tends to decrease but again it increases a little bit due to the reaction of the cam and follower mechanism and the compressive spring and tensile spring. Finally it ends with  $0 \text{ rev}/\text{min}$  where it the door stops moving. For acceleration as it is observed, there is an initial acceleration followed by a sudden decrease to the value 0.

There would exist a second condition too where the door snaps back. That is because

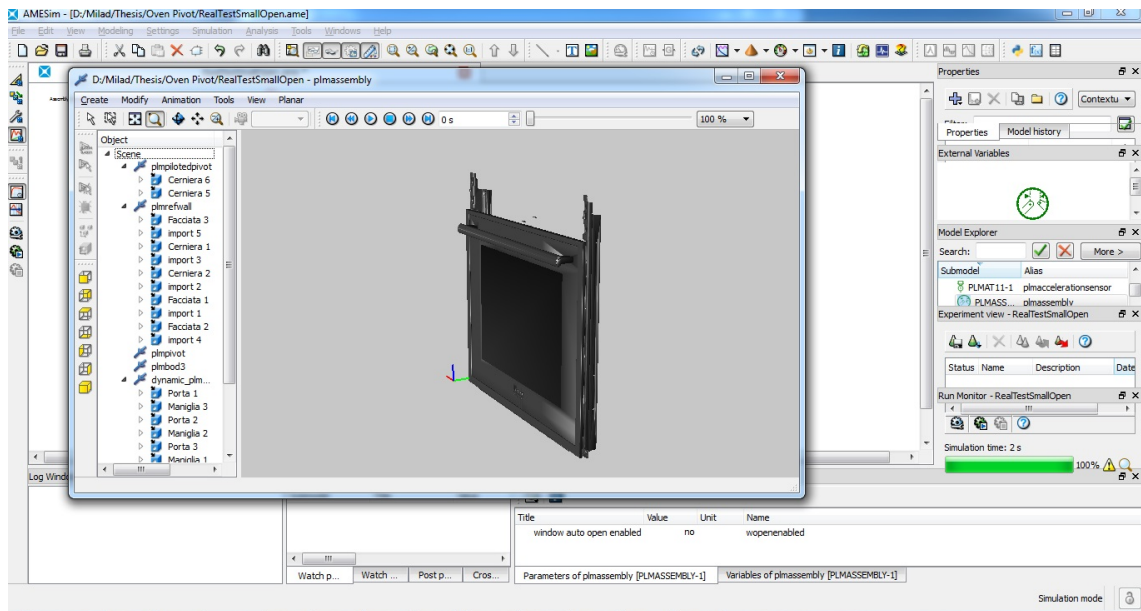


FIGURE 2.30: Assembly mode

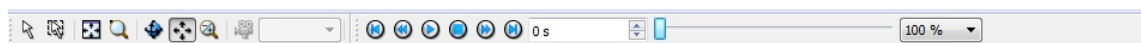


FIGURE 2.31: Assembly mode

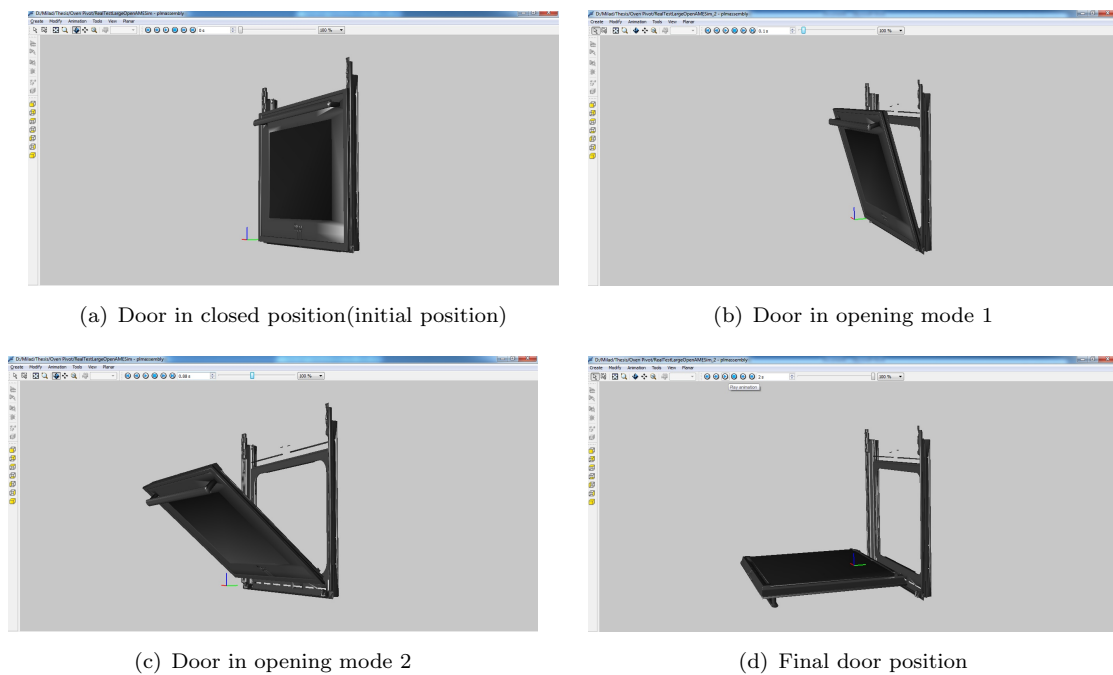


FIGURE 2.32: Animation of the opening-closing mechanism of the door of the oven with Large opening

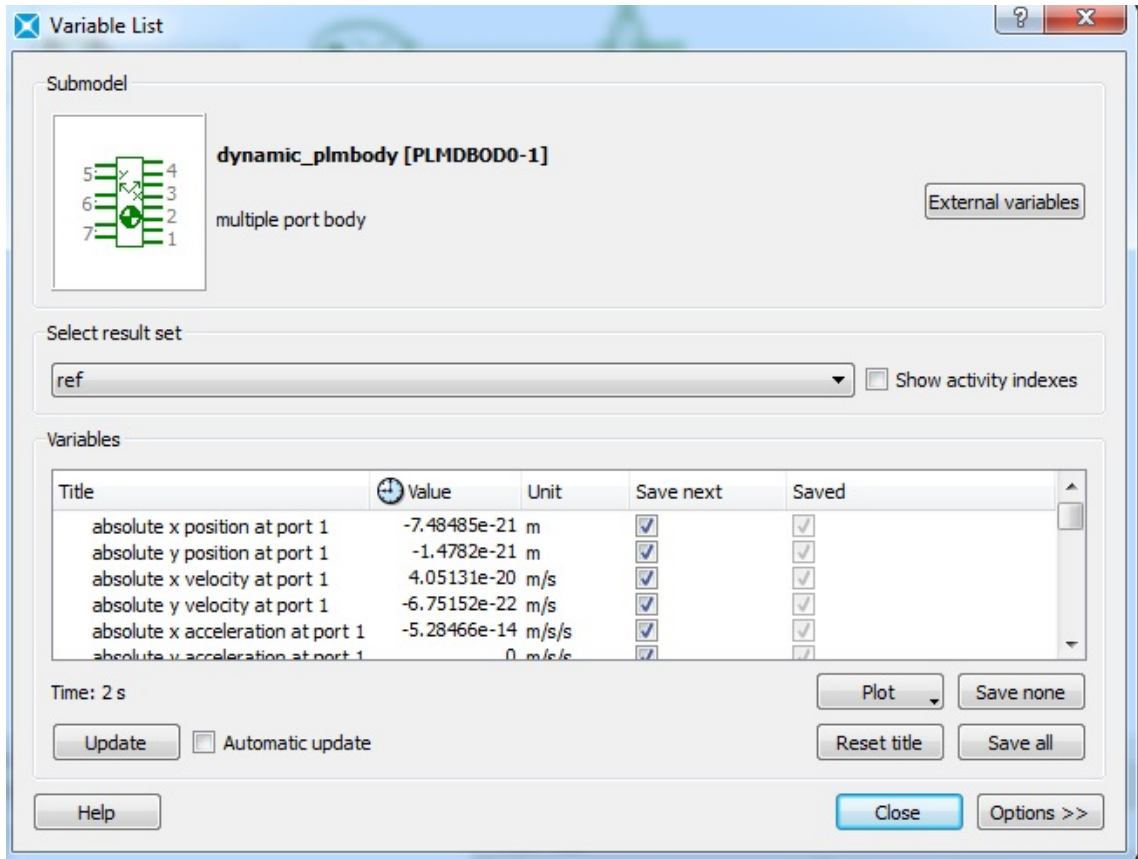


FIGURE 2.33: Stay-rod variable list

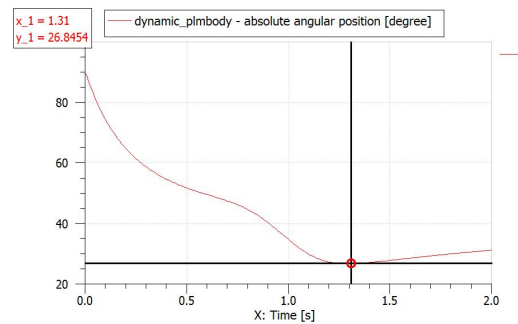
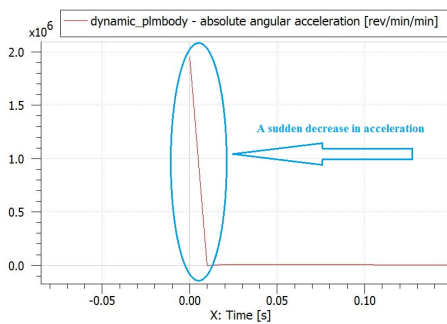
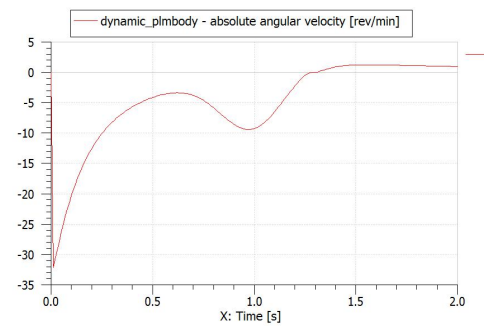
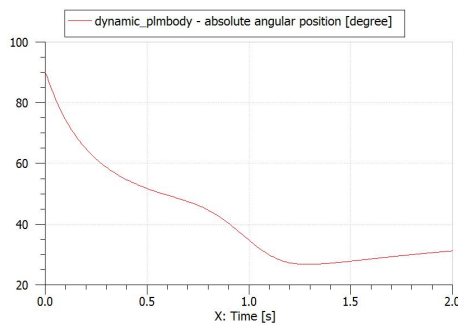


FIGURE 2.34: Graph for position, velocity and acceleration of the main body

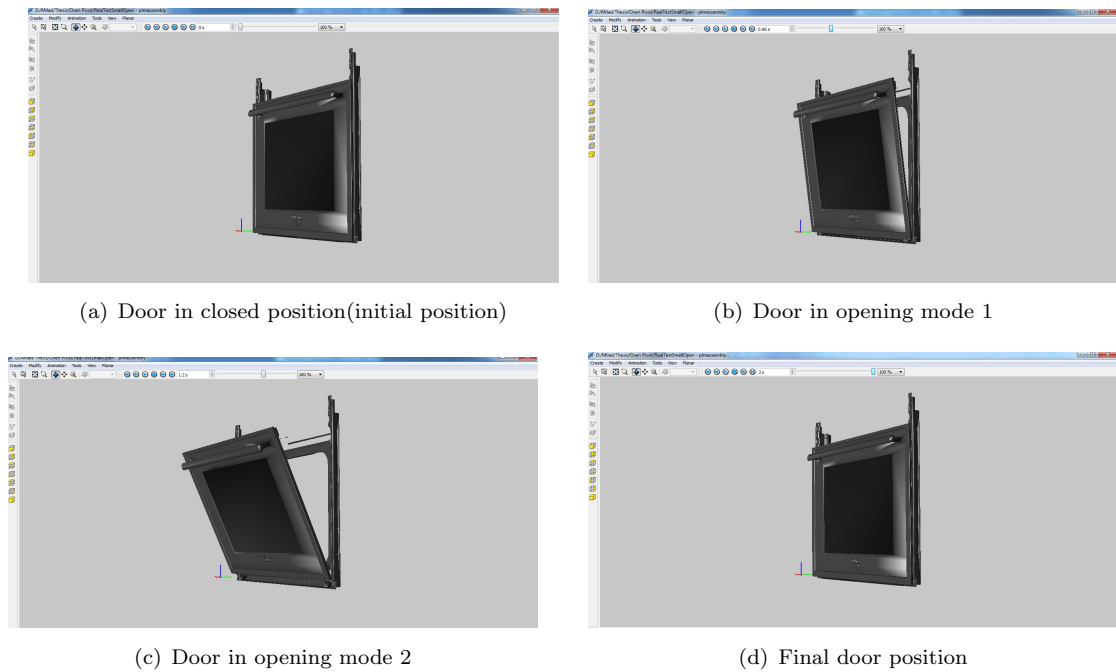
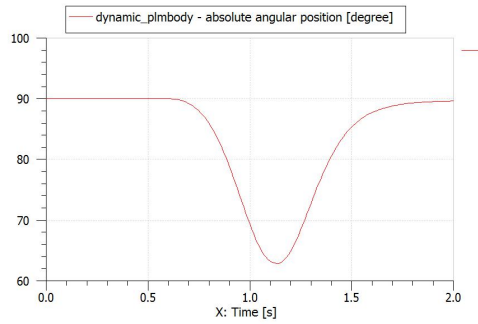


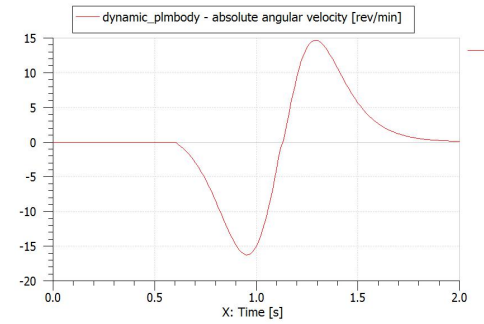
FIGURE 2.35: Animation of the opening-closing mechanism of the door of the oven with small opening

the force required to drive the door is not enough and the door opens maximum up to  $20^\circ$  to  $25^\circ$  and no more. To find the value of the force, a batch run has to be set and run in order to check when the door comes back to its original position and then check the corresponding force where in this case study is  $38\text{N}$ . So with the help of the new generation of Diplomat hinges it would be possible that the door travels the same distance backward thanks to the cam and follower mechanism and two tensile and compressive springs where apparently are preloaded (One stretched and one compressed). Then the graph for absolute angular position, absolute angular velocity and absolute angular acceleration varies according to the movement of the door where the animated picture is shown here.

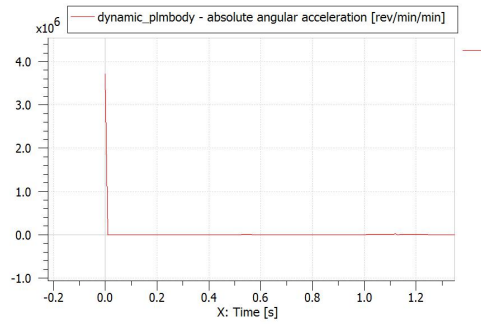
As can be seen in fig.2.36, apparently the initial angular position is at  $90^\circ$ . It decreases rapidly as time passes and reaches to the value  $62.9^\circ$ . Then it starts rotating upward. This reaction as explained before is due to the preloaded tensile and compressive springs and the cam and follower mechanism. So it tends to go back to  $90^\circ$  again. The parabola of velocity is exactly as expected before. There exists a rise and a fall that indicates the opening and closing of the door respectively. If we take a closer look at the velocity-time diagram, we will notice that the positive area above the time axis and the negative area below the time axis are the same. Indeed it means that the system does a symmetric movement. The magnitude of both peaks of the velocity diagram is the same (about  $16\text{rev}/\text{min}$ ). For acceleration diagram the situation is the same. The system profits



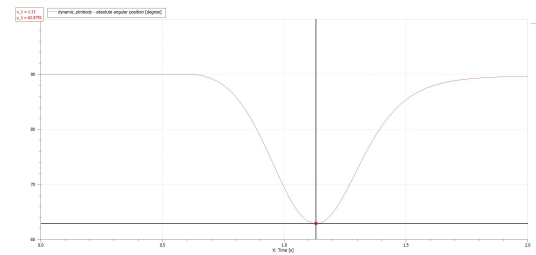
(a) Body angular position with snap back effect



(b) Body angular velocity with snap back effect



(c) Body angular acceleration with snap back effect



(d) Body angular position with its minimum point

FIGURE 2.36: Graph for position, velocity and acceleration of the main body with snap back effect

from an initial large acceleration followed by a steep fall.

In the next chapter, optimization of the oven will be discussed in detail.

## Chapter 3

# Optimization

### 3.1 Experiment

In first section of chapter three, it is being shown how to measure angular acceleration, angular velocity and load. The test starts with attaching three different sensors including the load sensor, the gyroscope and the accelerometer sensor to the different parts of the door of the oven. The sensors and the way they are attached to the oven are shown in fig.3.1.

The load sensor Model LTH300 is a *Donut Load Cell* built for Press or Inline compression applications.

We used a tri-axial accelerometer with sensitivity  $5.1 \text{ mv}/(m/s^2)$ , weigh 100 g, and a frequency range between 1 to 4000 Hz and with a titanium housing. Adhesive mounting is often used for temporary installation or when the test object surface cannot be adequately prepared for stud mounting.

The Vibrating Structure Gyro is a solid state rate sensor that is designed around a piezoceramic cup that can measure coriolis forces. This allows the VSG to produce a highly accurate output that is proportional to the rate of turn. Electronics for filtering, control, drive and demodulation are all packaged along with a single axis sensing element inside a small package. Wide ranges of input rates (up to 3000 per second) are available [11].

After installing the sensors, we start out the experiment by rotating the door of the oven from closed position to open position (inclined position). Thus we activate all the sensors simultaneously and start doing measurements for load, angular acceleration and angular velocity. Note that the output of the sensors is in mv that must be converted into v,

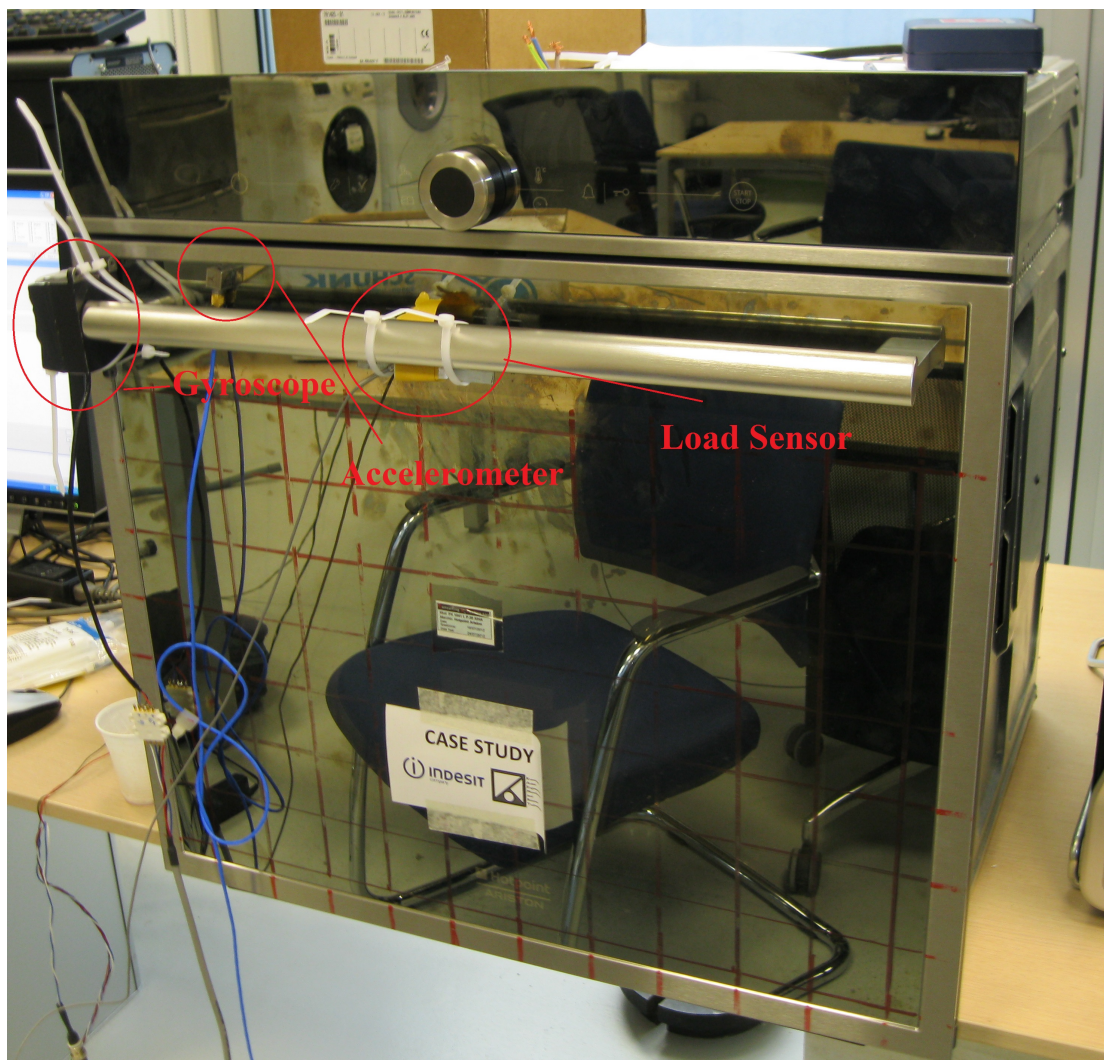


FIGURE 3.1: An overview of the sensors installed on the oven

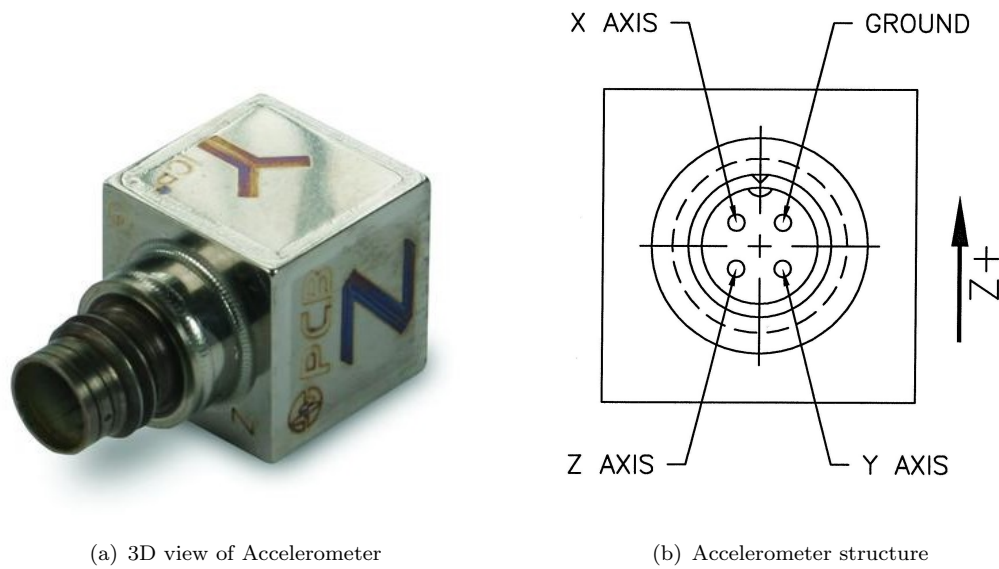


(a) FUTEK load sensor

(b) Load sensor structure

FIGURE 3.2: Load sensor

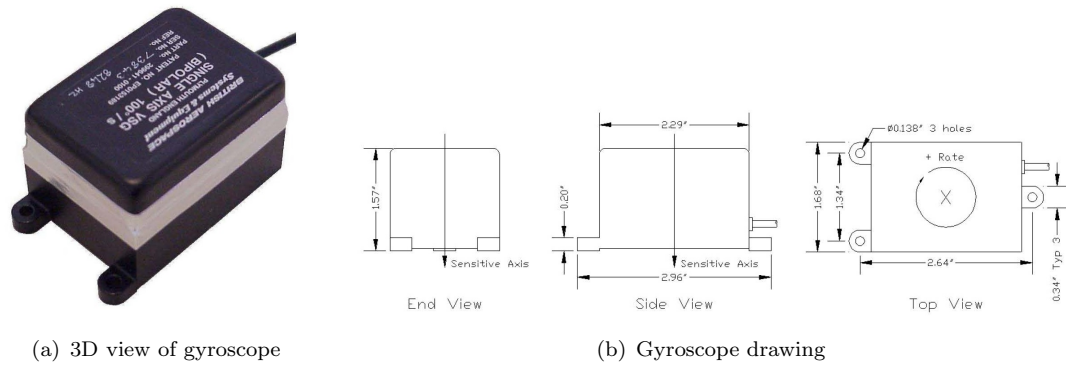




(a) 3D view of Accelerometer

(b) Accelerometer structure

FIGURE 3.3: PCB Piezotronics accelerometer



(a) 3D view of gyroscope

(b) Gyroscope drawing

FIGURE 3.4: Single Axis Watson VSG

then multiplied by a coefficient in order to change the unit from Volt to  $degree/s^2$ ,  $N$  and  $degree/second$  for acceleration, load and angular velocity respectively.

Measurements are stored in text files through the software *Labview NI*. The characteristics of the text file including four columns introducing time, acceleration, angular velocity and load respectively. The result of the one-time measurement is shown in fig.3.6.

The curve data are fitted because of presence of the noise. The parabolic data curves are fitted for angular acceleration, load and angular velocity. To do so, we use the software MATLAB and the function *cftool* to fit the curves.

Many functions like *Polynomial* (up to 19th order), *interpolant* function, *Gaussian* function, *Power* function, *Rational* function and etc. are tried. Gaussian curve fitting gives the best result figs.3.7., 3.8. and 3.9.

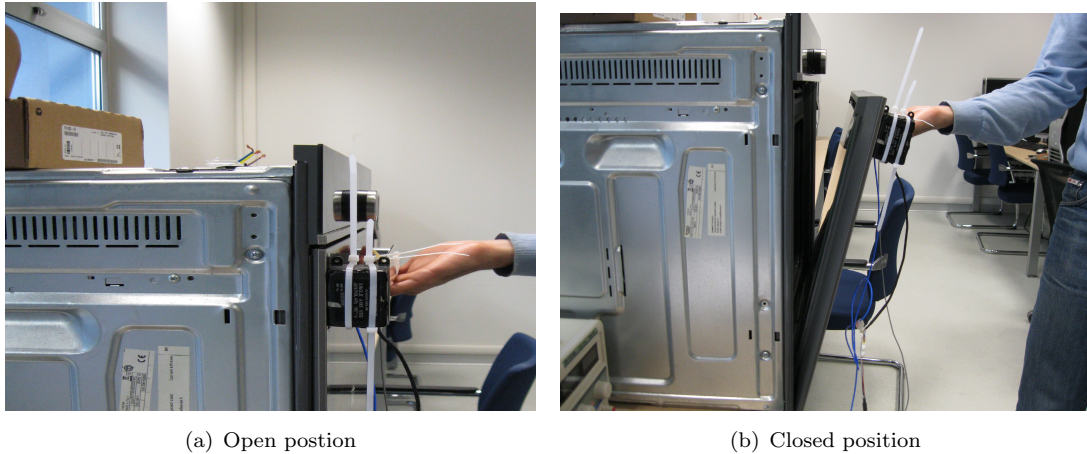


FIGURE 3.5: Initial and final position of the door of the oven

```

LabVIEW Measurement
Writer_Version 2
Reader_Version 2
Separator Tab
Multi_Headings Yes
X_Columns No
Time_Pref Absolute
Operator Milad
Date 2013/06/11
Time 18:51:36.163386
***End_of_Header***

Channels 4
Samples 10240 10240 10240 10240
Date 2013/06/11 2013/06/11 2013/06/11 2013/06/11
Time 18:51:36 18:51:36 18:51:36 18:51:36
Y_Unit_Label voltage (v) voltage (v) voltage (v) voltage (v)
X_Dimension Time (s) Time (s) Time (s) Time (s)
X0 6:50:44.320259574999 PM 6/11/2013 6:50:44.320259574999 PM 6/11/2013
Delta_x 0.000488 0.000488 0.000488 0.000488
***End_of_Header***
X_Value Voltage - cDAQ1Mod1_ai0 Voltage - cDAQ1Mod1_ai1 Voltage - cDAQ1Mod1_ai2 Voltage
0.000000 0.000112 2.515214 0.005713
0.000488 0.005848 2.514898 0.007944
0.000977 0.003617 2.511424 0.007944
0.001465 0.001386 2.516161 0.002207
0.001953 0.006804 2.515845 -0.001937
0.002441 0.002342 2.513635 -0.003530
0.002930 0.005529 2.512056 -2.431500E-5
0.003418 0.009353 2.511740 0.004119
0.003906 0.014133 2.516477 0.006350
0.004394 0.011265 2.516477 0.004438
0.004883 0.015726 2.514898 0.001888
0.005371 0.009672 2.511424 -0.000662
0.005859 0.009034 2.510477 -0.001299
0.006348 0.002024 2.516477 -0.001618
0.006836 0.007760 2.519003 -0.007037
0.007324 0.008716 2.517740 -0.008311
0.007812 0.011902 2.514898 -0.006399
0.008301 0.012540 2.513635 -0.003849

```

FIGURE 3.6: Experiment data

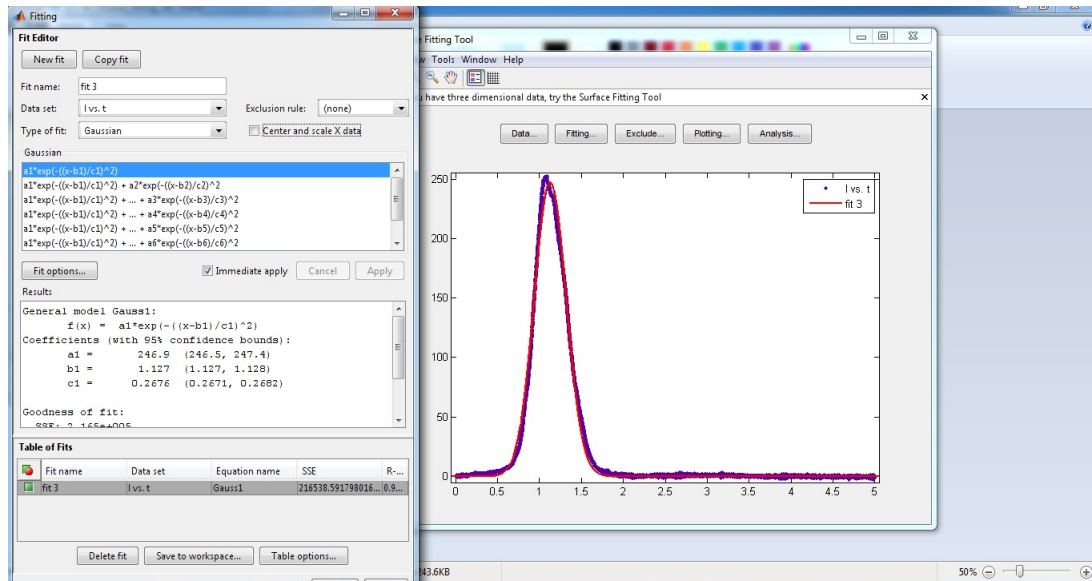


FIGURE 3.7: Curve fitting of load data vs. time

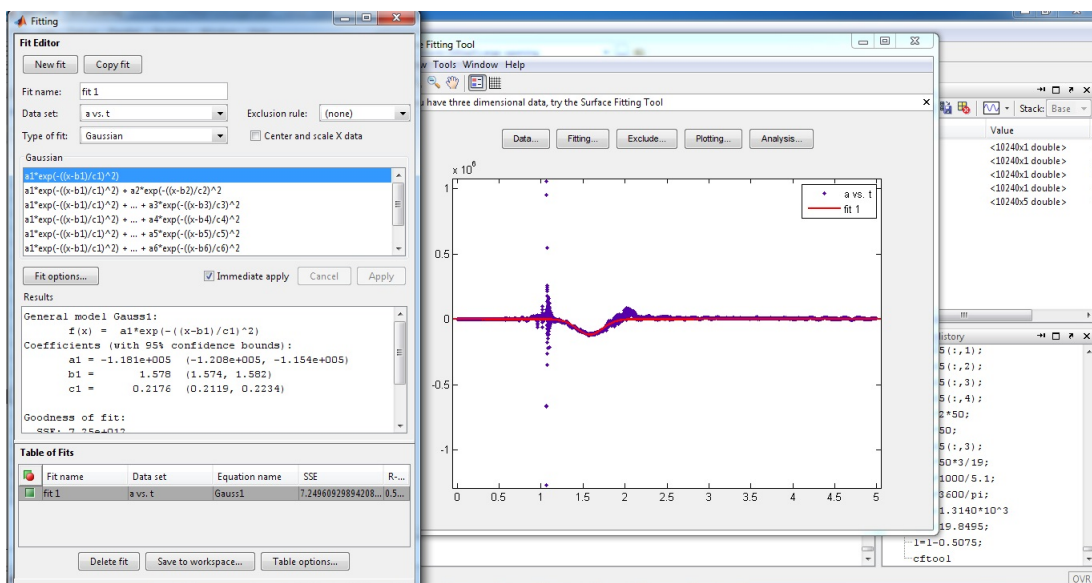


FIGURE 3.8: Curve fitting of acceleration data vs. time

In the next section it will be explained in detail how to implement the result of experiments in AMESim software and utilize the *optimization* package for *parameterization* of the system.

### 3.2 Optimization and parameterization of the case study

The load function is implemented in the *parameter mode* of the function block diagram. As we already know, the load is considered as an input.

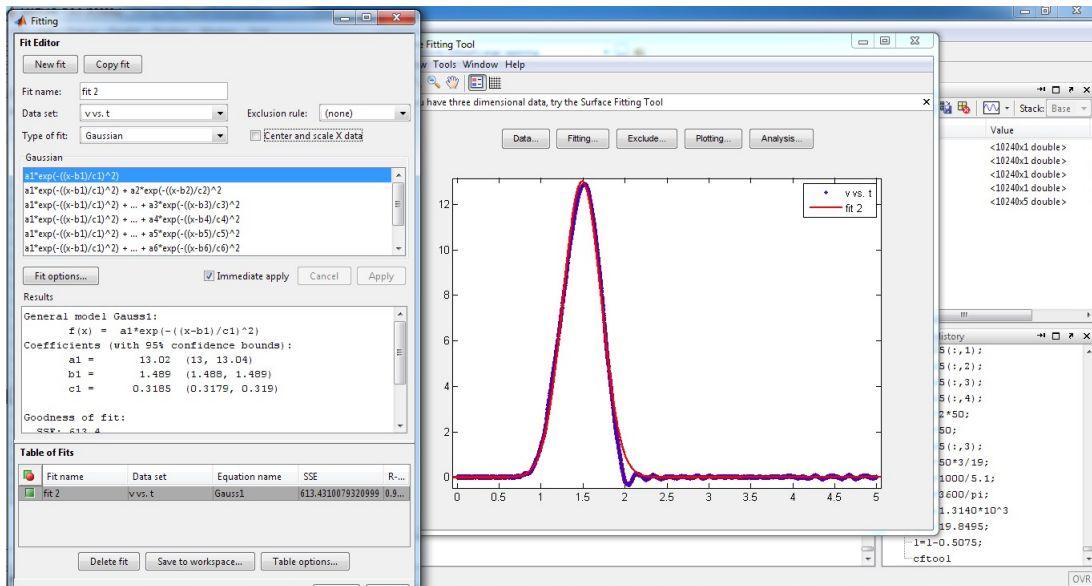


FIGURE 3.9: Curve fitting of velocity data vs. time

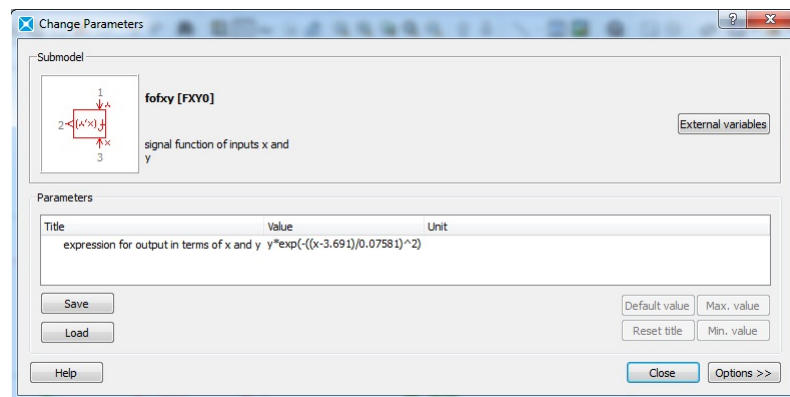


FIGURE 3.10: New load function  $f(x) = 356.8 \cdot \exp(-((x - 3.691)/0.07581)^2)$

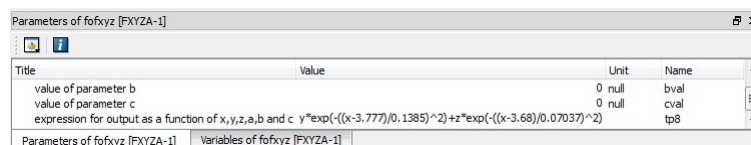


FIGURE 3.11: New load function  $f(x) = 356.8 \cdot \exp(-((x - 3.691)/0.07581)^2)$

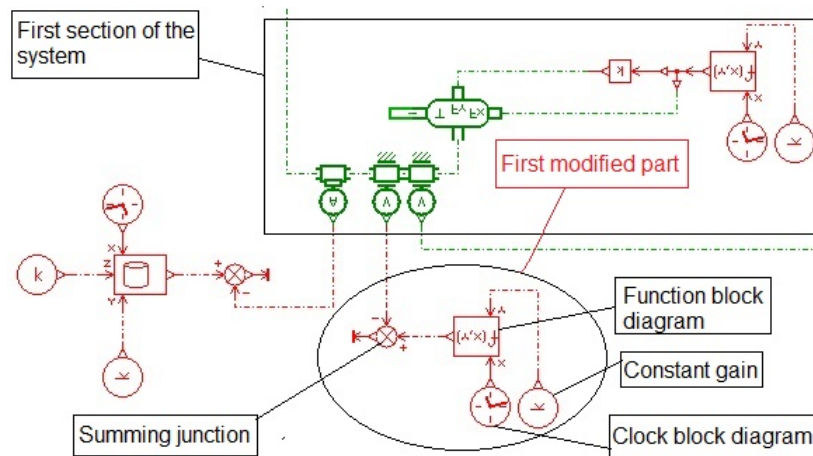


FIGURE 3.12: New load function  $f(x) = y \cdot \exp(-((x-3.777)/0.1385)^2) + z \cdot \exp(-((x-3.68)/0.07037)^2)$

Thus the first section of the system is modified properly. It means that the load function is inserted in the “parameter mode” of function block diagram. The velocity or acceleration of the model has to be compared with the velocity or acceleration values of the measurement performed in the previous section. So another section has been added to the model to insert the velocity or acceleration of the real model obtained by the measurement. We do this by selecting another set of block diagrams including a function block diagram, a clock and a constant gain. Besides, a “summing junction” is needed to compare the two results meaning the results of the model and the ones of the measurement.

Take note that the goal of the optimization is based on minimizing the output of the summing junction as close as possible to the value zero. Actually this is why “summing junction” icon is placed in the modified system. Because the output of the summing junction is the subtraction between the velocity (or acceleration) of the model with velocity (or acceleration) of the measurement.

### 3.2.1 Export

In AMESim we talk about submodel parameters, global parameters and submodel variables. For the export module we talk about input and output parameters.

*Input Parameters* are values associated with a name that are directly or indirectly needed by the simulation to run. Every submodel parameter visible in Parameter mode and every global parameter of a model can be used as an export input parameter fig.3.15.

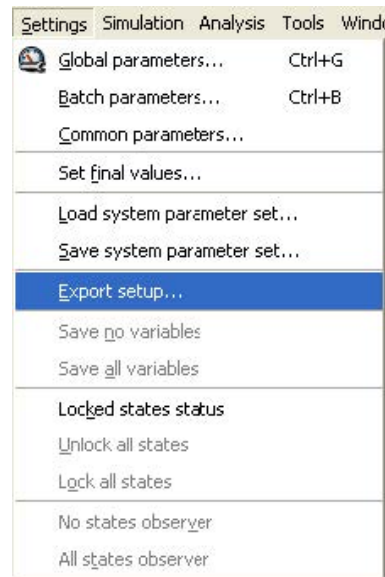


FIGURE 3.13: Export setup

*Output parameters* are values associated with a name that are produced by the simulation or that are computed from other output parameters. Every submodel variable could be used as an export output parameter. Such outputs are called Simple Output Parameters fig.3.16.

*Compound Output Parameters* are post-treated outputs: they are computed from user defined expressions which involve any export Input Parameters, Simple Output Parameters or other Compound Output Parameters. Certain functions may also be used fig.3.17

When using AMESim and other commercial design exploration/optimization software, the *Export* facility is used first. Using this tool, it is easy to change the parameters of the model and get post-treated results of the simulation. The Export facility sets up parameters in a format suitable for *AMEPilot*.

### Setting up the export

First we shift into *Parameter mode*. So an Export Parameters Setup dialog box is created. Note that there are three tabs. Input Parameters section is currently selected.

### Set the parameters needed for the export

The aim of optimization is to modify the values of every element used in the hinge. So stiffness of both springs and amount of springs preload besides the friction force in different parts of the hinge are selected as input fig.3.15. The names of the selected parameters are changed according to their functionality.

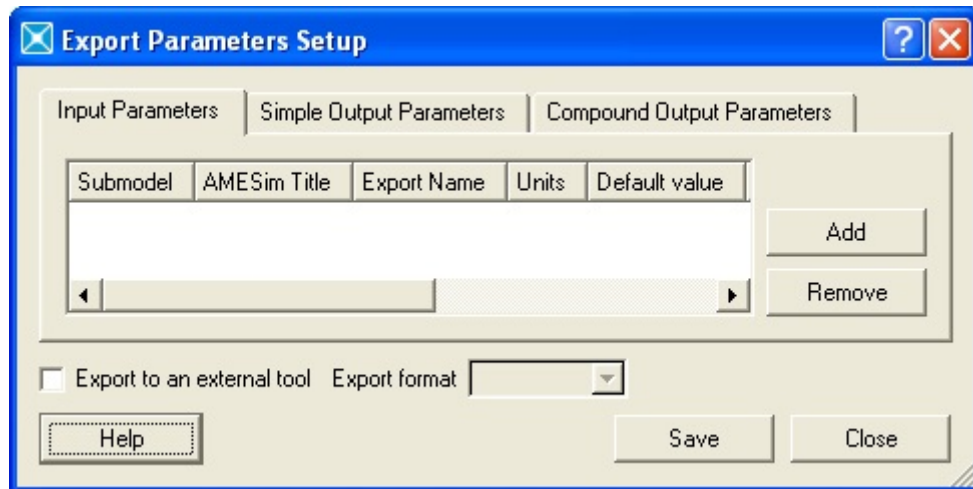


FIGURE 3.14: Export setup

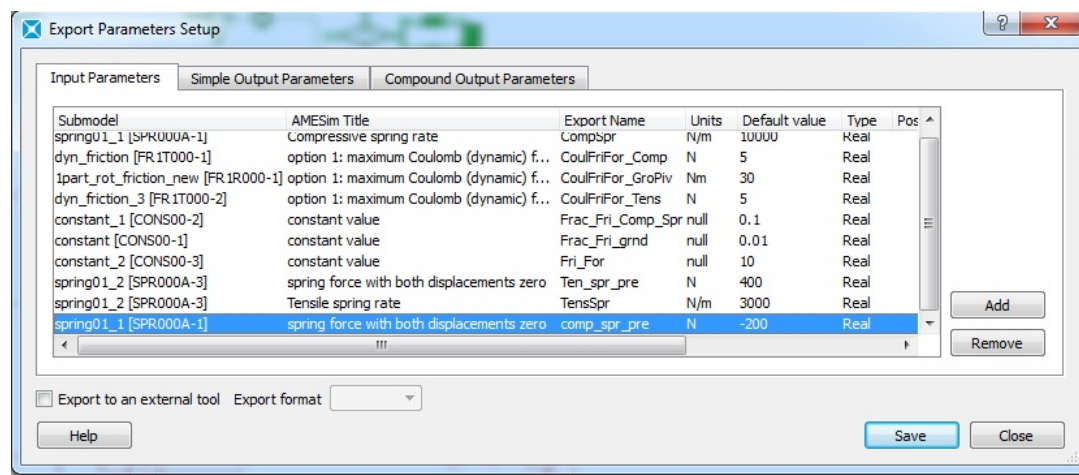


FIGURE 3.15: Input parameters

By default the value types are *Real* values. The export parameters will be accessible outside of AMESim. As said before we edited the Export Name and Default value fields as what we calculated in the second chapter. We switch to the *Simple output parameters*. Put the output from the summing junction in this section and change the name into *Dif\_in\_vel3.16*.

The aim of optimization is to approach two different systems meaning the real system and the modeled system. Thus several criteria could be used in order to be posed inside the system. We have to minimize either:

1. Maximum difference between the velocity (or acceleration) of the real system and of the model,

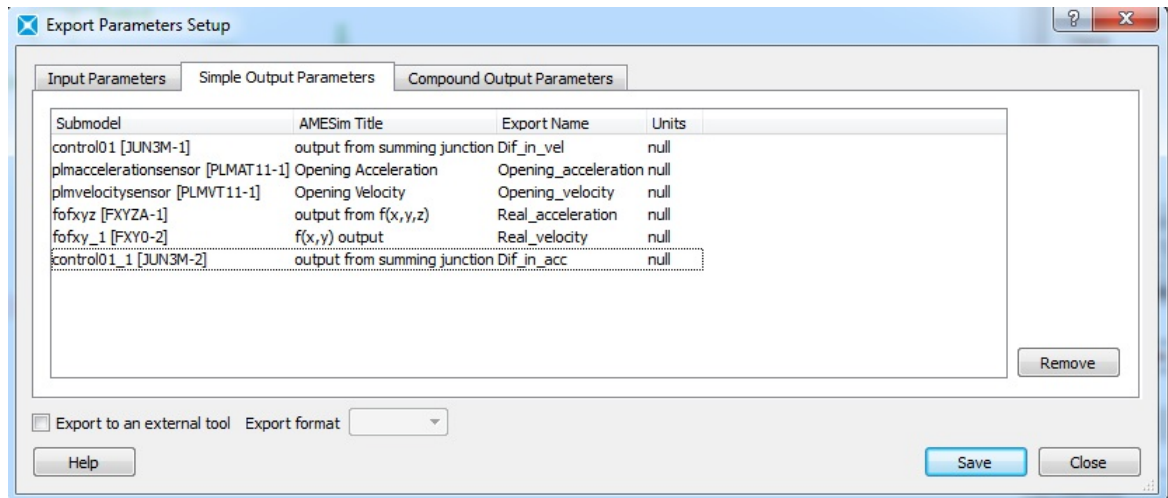



FIGURE 3.16: Simple output parameters

2. Maximum squared difference between the velocity (or acceleration) of the real system and of the model,
3. Final value of the integral of absolute difference between acceleration (or speed),  
or
4. Final value of the integral of squared difference between acceleration (or speed).

Finally we change the tab to *Compound output parameters* and eight expressions are formulated according to the optimization criteria mentioned before. Four of them belong to optimization through velocity criteria and the other four belongs to optimization through the acceleration criteria fig.3.18.

In the next step we use the optimization tool in the software LMS AMESim.

Therefore we enter the design exploration by Select Analysis and then Design exploration or click on the Design exploration button  to produce the Design Exploration dialog box.

Then we right-click on *Optimization* and click on *New study* and then in the new window *Design exploration definition* appears. We leave the lower bound and upper band as what defined by default. Because as explained earlier in the overview, the state of the art consists in first performing a global optimization (genetic algorithm) in order to explore the design space and to avoid local minima, and then to extend the study with a local algorithm (NLPQL) to refine the convergence.

At the end of optimization process, the optimized input parameters are given in the table 3.1. The best solution found is through the fourth criterion which is minimizing‘



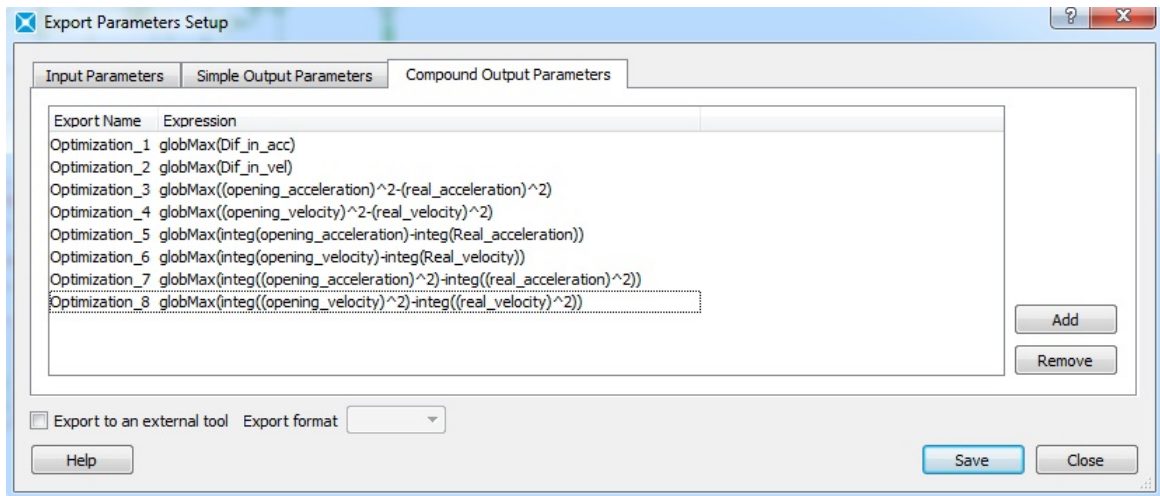


FIGURE 3.17: Compound output parameters

Export Name	Expression
Optimization_1	globMax(Dif_in_acc)
Optimization_2	globMax(Dif_in_vel)
Optimization_3	globMax((opening_acceleration)^2-(real_acceleration)^2)
Optimization_4	globMax((opening_velocity)^2-(real_velocity)^2)
Optimization_5	globMax(integ(opening_acceleration)-integ(Real_acceleration))
Optimization_6	globMax(integ(opening_velocity)-integ(Real_velocity))
Optimization_7	globMax(integ((opening_acceleration)^2)-integ((real_acceleration)^2))
Optimization_8	globMax(integ((opening_velocity)^2)-integ((real_velocity)^2))

FIGURE 3.18: Simple output parameters

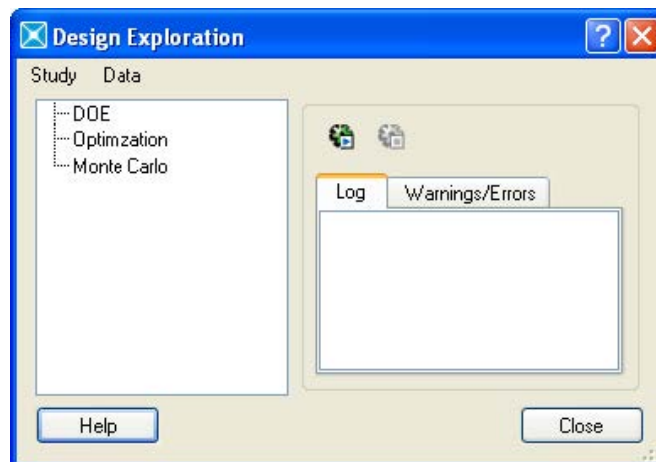


FIGURE 3.19: Design exploration dialogue box

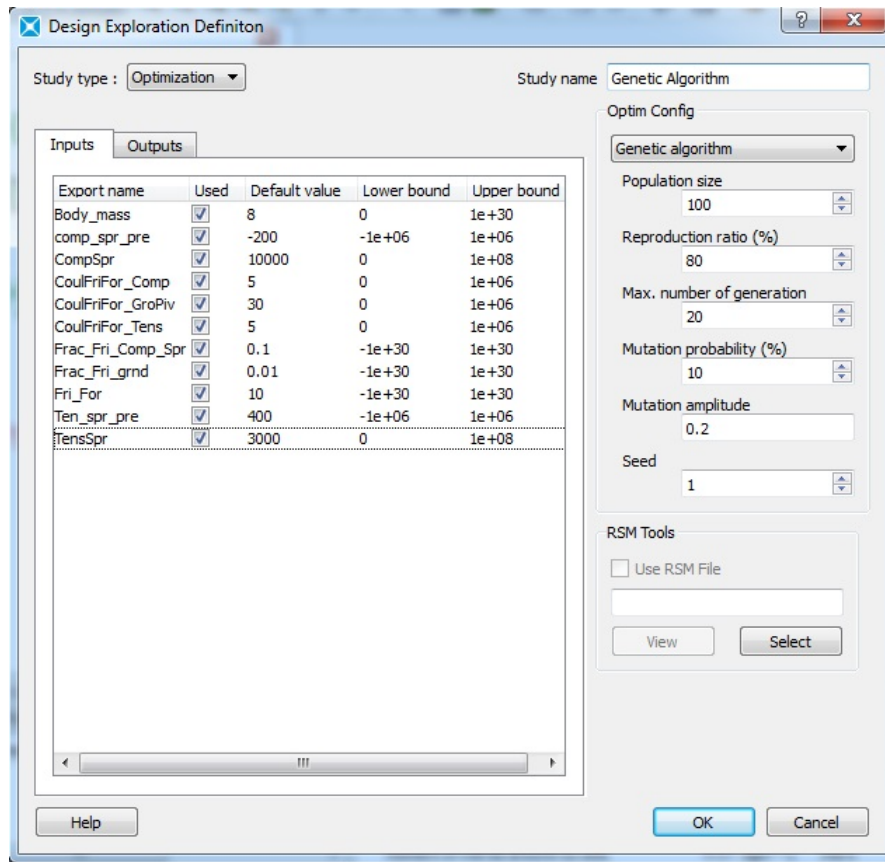
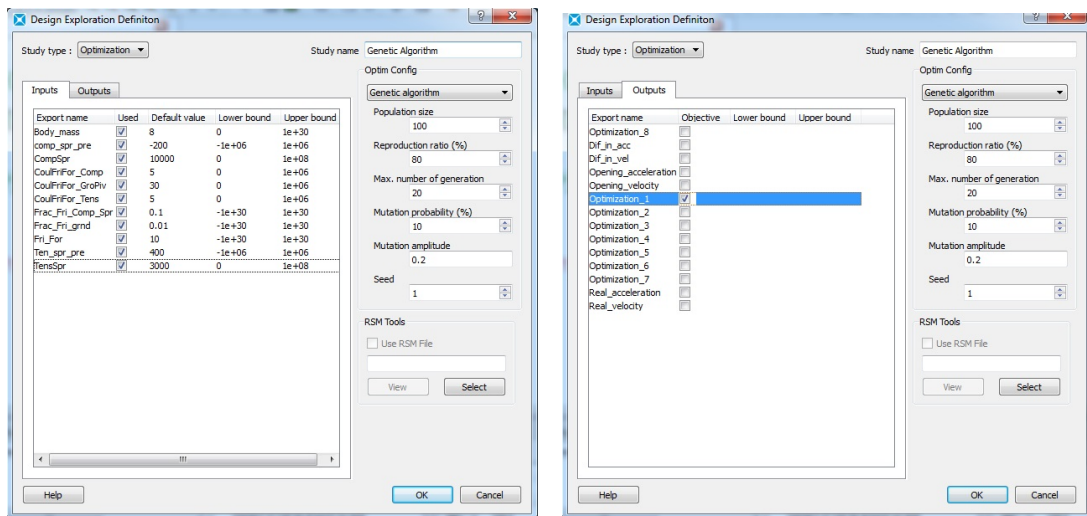


FIGURE 3.20: Genetic Algorithm



(a) Optimization input

(b) Optimization output

FIGURE 3.21: First optimization based on the Genetic Algorithm

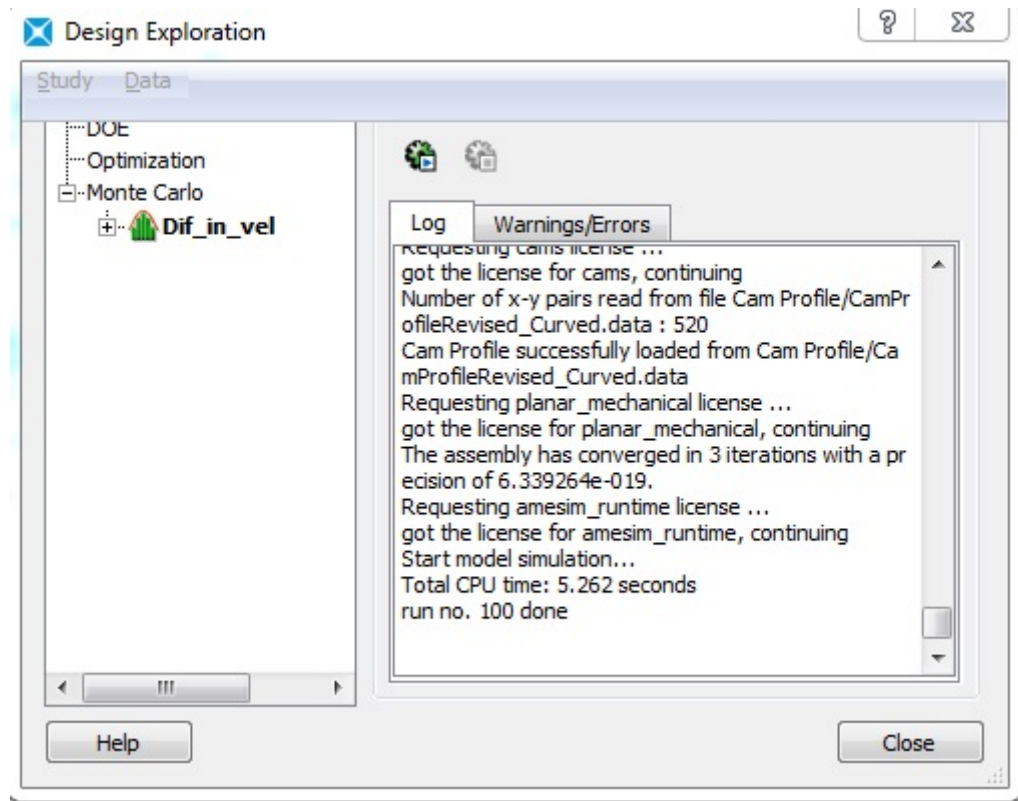


FIGURE 3.22: Solution progress dialogue box

TABLE 3.1: Best solution found via the criterion minimizing “final value of the integral of squared difference between speed of the modeled system and that of the real experiment”.

Compressive spring stiffness	2.61508737392910e+003
Tensile spring stiffness	2.09336993819491e+003
Maximum Coulomb friction force for compressive spring	1.11562549751767e+001
Maximum Coulomb friction force for compressive spring	7.70230749470754e+001
Maximum Coulomb friction force for ground pivot	2.56671657452170e+000
Fraction of maximum friction force for ground pivot (between 0 and 1)	1.28638611059235e-001
Friction force for the tensile spring	3.39469034866910e+001
Fraction of maximum friction force for compressive spring (between 0 and 1)	3.58883552616509e-001
Tensile spring preload	5.82768015744605e+001
Compressive spring preload	-6.76591341123854e+001
Optimization error	3.75098995130593e-001

‘final value of the integral of squared difference between speeds of the real model and the simulated one. Because the optimization error is no more than 0.38% according to the table 3.1 while in other criteria the error exceeds 5%.

The velocity graphs for the real hinge and modeled hinge are illustrated here in fig.3.23.

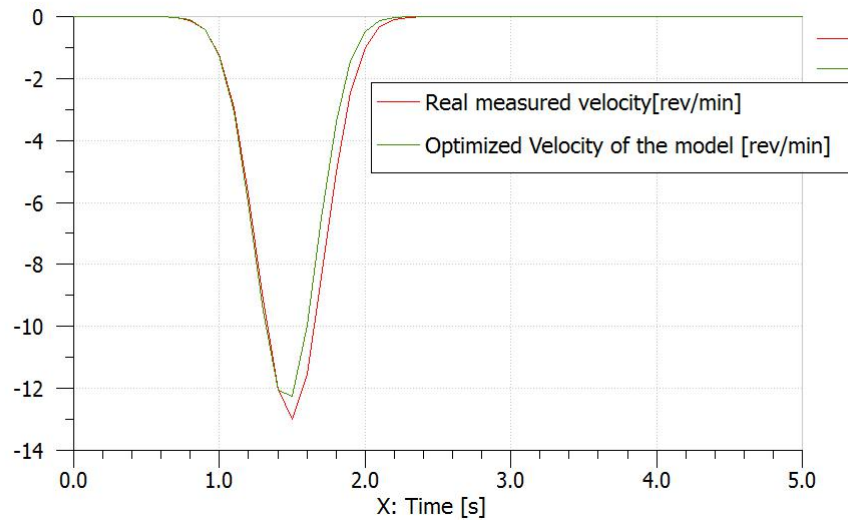


FIGURE 3.23: Optimized velocity of the model vs. Real velocity obtained by measurement

### 3.3 A Model of the User as a Mechanical Load

At the beginning of this section the concept *mechanical impedance* is explained clearly because the following models presented here are based on mechanical impedance of the user. Impedance is nothing rather than a resistance or stiffness in materials. The materials that are soft have lower impedance while the more stiff ones have higher impedance. Humans mechanical impedance depends greatly on the type of grasp thus three categories of grasps are defined here.

1. *contact grasp* which is touching an object with one finger or even with the whole palm of the hand,
2. *precision grasp* which is holding an object in a precise way. It is usually done with two fingers one thumb and the other acts as a holder,
3. *power grasp* which is holding an object tightly and is normally done with whole fingers in the sense that thumb is used as a counter bearing and the rest of the fingers to hold a knob or a handle firmly.

#### 3.3.1 Model

**KERN** [12] defined an eight-element model fig.3.24 for measuring the impedance. The model can be classified in three different groups used for many grasping situations:  $\underline{Z}_3$

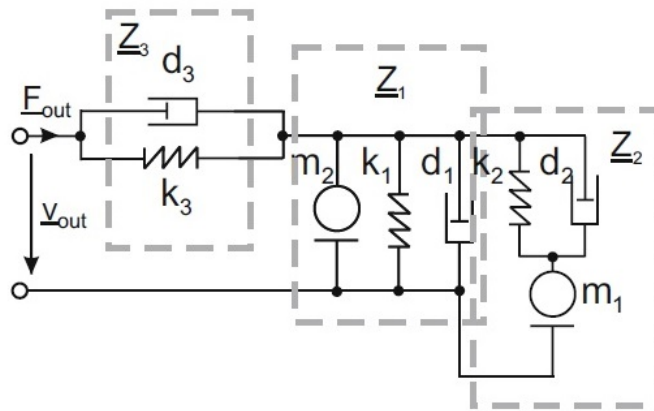


FIGURE 3.24: Eight-element model of the user's impedance, modeling the passive mechanics for frequencies  $>20$  Hz.

models the elasticity and damping of the skin that is in direct contact with an object (handle in this case study).  $Z_1$  is the central element of the model and depicts the mechanical properties of the influencing body parts - normally fingers.  $Z_2$  gives an insight into the mechanical properties of the limbs, usually hands. This model also lets up to assume an amount of preload in the joints.

The Kerns electrical board is used to obtain the generated output value  $F_{out}$  which

The eight-element model of the user's impedance proposed by **kern** is modeled in the AMESim for the first time. In fact several block diagrams are used to simulate the Kerns electrical circuit. Thus the block diagrams listed here are connected in fig.3.26 in AMESim.

1. "Clock" in order to simulate the time,
2. The "function block diagram" to insert the formula of humans impedance transfer function which will be discussed in section "impedance measurement parameters",
3. A "division block diagram",
4. A "splitter junction" to share the force exerted in both  $x$  and  $y$  directions of the handle.

$$\underline{Z}_1 = \frac{s^2 m_2 + k_1 + d_1 s}{s} \quad (3.1)$$

$$\underline{Z}_2 = \left( \frac{s}{d_2 s + k_2} + \frac{1}{s m_1} \right)^{-1} \quad (3.2)$$

$$\underline{Z}_3 = \frac{d_3 s + k_3}{s} \quad (3.3)$$

$$\underline{Z}_B = \underline{Z}_1 + \underline{Z}_2 \quad (3.4)$$

According to the transfer function  $\underline{Z}_H$  and the formula

$$\underline{G}_{H3} = \frac{v_{spo}}{F_{out}} \quad (3.5)$$

$$= \frac{v_{out} - v_{ind}}{F_{out}} \quad (3.6)$$

$$= \underline{Y}_H \quad (3.7)$$

$$\therefore \quad (3.8)$$

$$= \frac{1}{\underline{Z}_H} \quad (3.9)$$

The generated output value  $F_{out}$  is calculated by multiplying the velocity by the mechanical impedance according to the equations 3.5 and 3.9. The velocity is obtained by getting the signal from the “velocity sensor” which was implemented in the first part of the model and the mechanical impedance is measured by performing a measurement. The value of the mechanical impedance will be obtained from section “Impedance measurement parameters.”

This model could be substituted by the real or evaluated load parameter implemented in the second chapter by the use of signal library and mechanical library for conveying the force to the input system.

### Impedance measurement parameters

The acquisition of mechanical impedance is a daily problem. The main principle to acquire mechanical impedance is to apply an excitation to the system and measure the corresponding output force and velocity at the same time.

KERN[13] performed the impedance measurements based on a sinoid-sweep frequencies. The excitation is made with a specified force of 2N amplitude at the sensor and accordingly the mechanical impedance of the sensor is measured fig.3.30. The following table 3.29 provides the parameters for the model illustrated in fig.3.24.

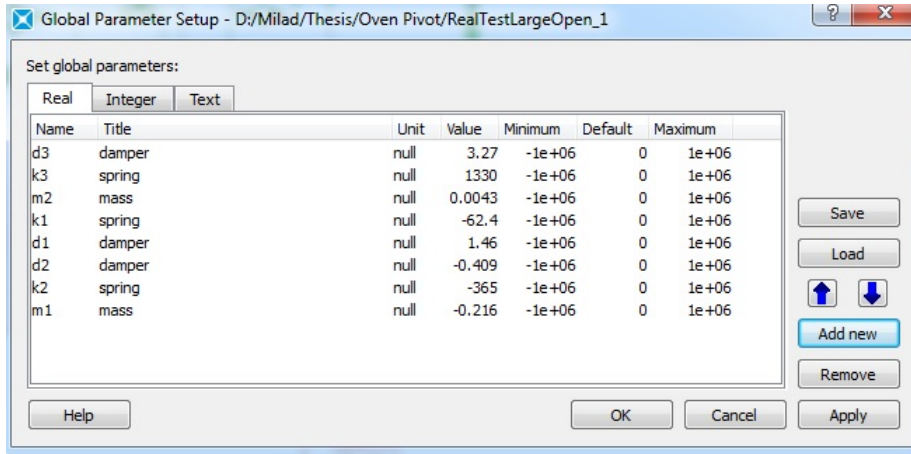


FIGURE 3.25: Global parameter setup dialog box

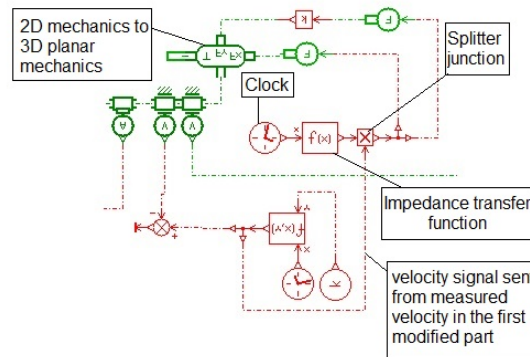


FIGURE 3.26: Hand user elements implemented in AMESim

$$\underline{Z}_H = \underline{Z}_3 \parallel \underline{Z}_B \quad (3.10)$$

$$\therefore \quad (3.11)$$

$$= \left( \left( \frac{s^2 m_2 + k_1 + d_1 s}{s} + \left( \frac{s}{d_2 s + k_2} + \frac{1}{s m_1} \right)^{-1} \right)^{-1} \right)^{-1} \quad (3.12)$$

In Parameter model fig.3.28 the function is based on the equation of mechanical impedance acquired from equ.3.12.

These parameters are shown here in fig.3.29 are transferred into the *Global parameter setup* dialog box fig.3.25.

The plot of the force for **Power grasp** meaning holding an object with at least one finger and a counter-bearing is shown in fig.3.31.

## Results

According to the fig.3.31. the generated output value  $F_{out}$  is about 550N which is the force along the tissues including the limbs, muscles and etc.

Based on the results obtained in the second chapter the maximum force applied is about 250N. If we make a comparison between these two results, it is being found that the internal force along the tissues of bodys hand is about 2.2 times more than the external force applied to the handle of oven. It means that as estimation half of the force is damped when it exerts to the handle. It could be due to the numerous bones, muscles and limbs which are implemented in hand membrane. The hand itself contains 27 bones and 33 muscles. Also we can think of action potential [14] of systems physiology that is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls following a consistent trajectory.



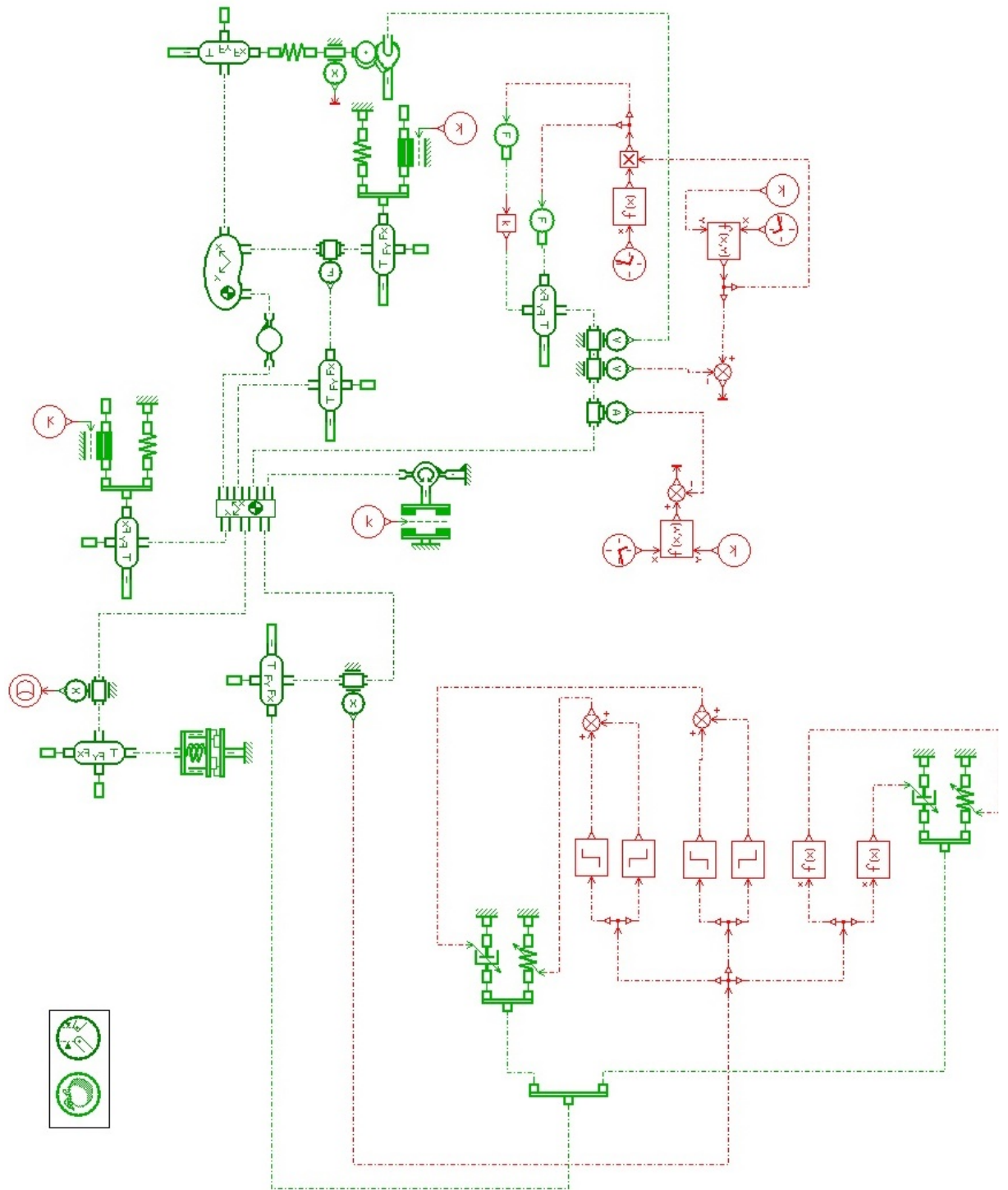


FIGURE 3.27: Hand user elements implemented in main model

Parameters		
Title	Value	Unit
expression in terms of the input x	$(x/(d3*x+k3))+((x^2*m2+k1+d1*x)/x+(x/(d2*x+k2)+1/(x*m1))^{-1})^{-1}$	

FIGURE 3.28: The mechanical impedance function in parameter mode

Grasp/touch	$k_1$	$m_1$	$d_1$	$d_2$	$k_2$	$k_3$	$d_3$	$m_2$
	[N/m]	[kg]	[Ns/m]	[Ns/m]	[N/m]	[N/m]	[Ns/m]	[kg]
<b>Power grasps</b>								
Cylinder	412.61	1.577	43.43	33.06	31271	15007	182.77	0.13
Sphere	2500.7	4.32	45.72	31.35	21033	9743	150.60	0.098
Ring 17.71	10.0	0.0032	31.35	5843.7	2906.7	34.54	0.016	
<b>Precision grasps</b>								
Pen 45°	1357.1	1.7376	23.38	3.269	36672	3544.6	12.22	0.029
Pen vertical	44.73	5.44	4.55	17.92	17794	1782.7	12.92	0.029
Pen horizontal	212.49	3.26	7.56	8.15	22092	3672.7	13.73	0.043
<b>Finger</b>								
normal 2mm	203.21	75.02	1.0854	3.1672	6656.0	478.73	8.3689	0.0114
normal 15mm	0.091	37.28	3.79	3.18	9273.5	839.92	12.22	0.018
shear lateral	54.5	10.0	0.323	4.88	12935	191.62	4.4342	0.0178
shear distal	77.56	9.892	9.443	3.003	22874	2004	4.0377	0.0195
shear 45°	1053.0	90.44	5.47	7.16	26854	1090.2	15.26	0.006

FIGURE 3.29: Mean values of the mechanical impedance model according to figure 3.24 for different grasping situations

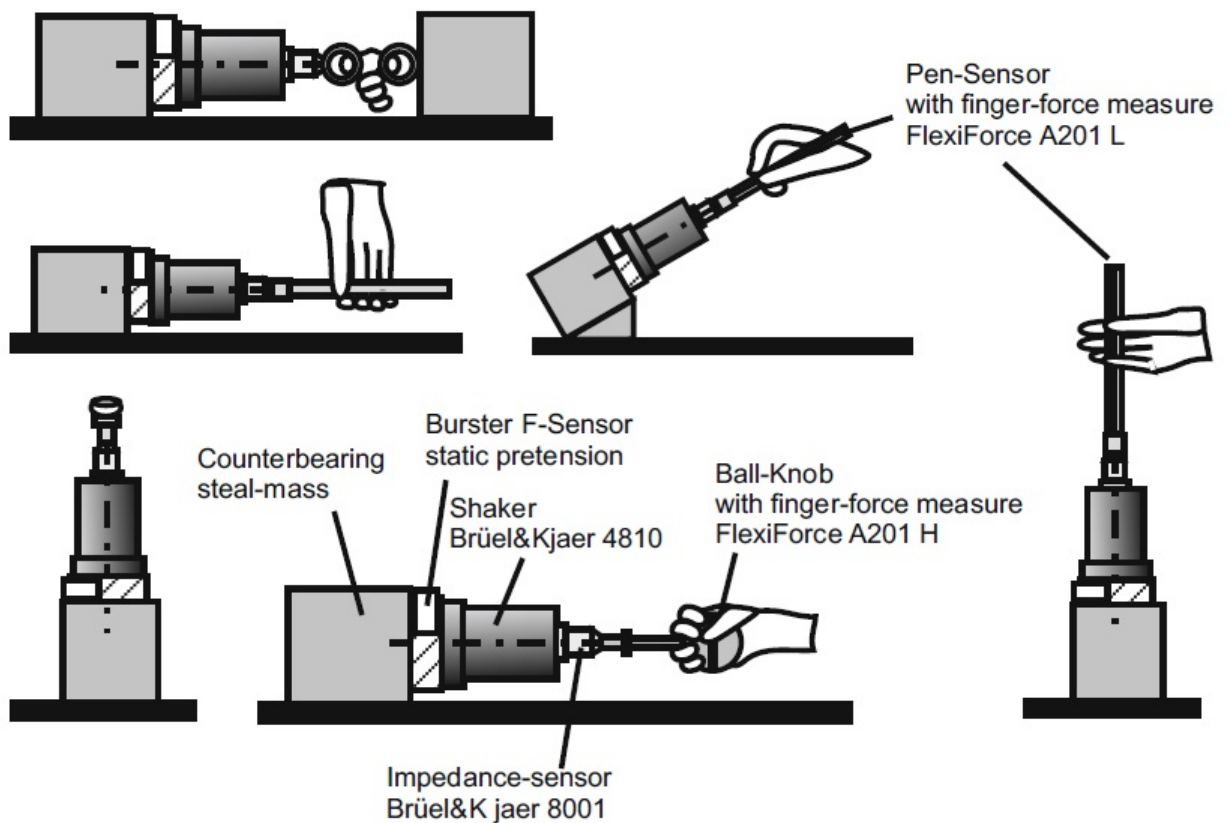


FIGURE 3.30: Impedance measurement settings for different grasps [13]

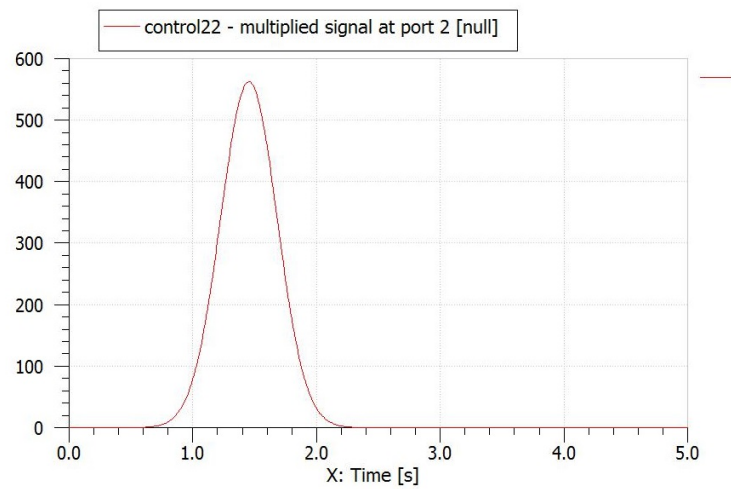


FIGURE 3.31: The plot of the force exchanged between finger-tip, bones and muscles

## Chapter 4

# Conclusion

The new technology “*Virtual Prototyping*” as its name offers is about building virtual prototypes. This method challenges what was believed as traditional “*product design process*” in the sense that the demanded model or needed system could be simulated by means of software and several different analyses could perform on the virtual model.

The case study is about simulation and optimization of an oven hinge through the software LMS AMESim. After understanding how the mechanism works, the process of its simulation starts. Icons belonging to different categories are connected through their ports to simulate the movement of the hinge in detail. The proper parameters are calculated for each block diagram like the stiffness of the compressive and tensile springs. Then we let it move into running the simulation. In the next step the CAD models are imported from the software Solidworks into AMESim to have a 3D perception of the mechanism assembly and how it moves. Optimization via a combination of genetic algorithm and NLPQL methods is done based on the criterion “minimizing final value of the integral of squared difference between speeds of the real model and the simulated model. So an experiment is done to find out the real values of the input force and the corresponding outputs velocity and acceleration.

After simulation we have access to the data regarding the acceleration, velocity and position of the door at every moment. Furthermore we can read the information regarding the followers displacement and the associated force necessary to apply with the aim of expected reaction of the door. After performing optimization, a collection of the best data is gathered then the proper values of each component used in the system are allocated. In the last part it is being illustrated that the force which is applied by the hand of the user is in Gaussians shape verifying the experiment we did in the second chapter.

In the last part the modeling of a user as a mechanical load in sense of modeling the hand of a user (in case of an oven it would be a power grasp) in AMESim thanks to the KERNS eight element circuit and analogous of electrical and mechanical systems. Also this field is expandable to other research field areas such as automobile industry. The companies might be interested in simulate a virtual hybrid car and let it be driven in a virtual path to be informed how many liters benzene or gasoline is needed to be fueled.

Nowadays companies are pushed into launching their products with the aim of first “lower cost process” and second “spending less time”. In order to achieve this goal, “Virtual prototyping” could be used as an interface among engineers and products.

# Appendix A

## References

- [1] Tong C, Sriram R. Artificial intelligence in engineering design, vol.1. Academic Press; 1992 (Chap. Introduction)
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