MHD Omar AL Soufi:
Postgraduate Student, Department Mechanical power, Faculty of Mechanical Engineering, Al-Baath University, Homs, Syria.
Muhammad Bashar Moeini
Professor, Department Mechanical power, Faculty of Mechanical Engineering, Al-Baath University, Homs
Salah Al-Shamali:
Associate Professor, Department Mechanical power, Faculty of Mechanical Engineering, Al-Baath University, Homs
Akl Mandow:
Associate Professor, Department Mechanical power, Faculty of Mechanical Engineering, Al-Baath University, Homs

MODELLING A GAS TURBINE BLADE USING REVERSE ENGINEERING

Abstract: *Gas turbines play a major role within power plants. The main function of blades in gas turbines is to transfer or extract energy. Because the primary function of blades is to smoothly change the velocity of fluid flow, it generally consists of surface patterns carved so precisely and so complicated that making from model formation by conventional methods is not recommended and the resulting pattern will be impractical.*

In the case of absence of design data, the reverse engineering process can be considered as the main tool for modelling to access the design information. The process of reverse engineering involves sensing the geometry of the current studied part to be designed, creating an engineering model of the part from the computed data and passing this model to a suitable CAD/CAM system for manufacturing. This study mainly deals with the modelling of gas turbine blades. The turbine blade design data are obtained using reverse engineering technique. With the obtained *data, a model of the turbine blades is created in SolidWorks with the help of a 3D laser scanner.*

Key words: *reverse engineering, blade of gas turbine, First stage, modelling, blade.*

MHD Омар Аль Суфи:
аспирант кафедры Механическая энергетика Механического факультета Инжиниринг, Университет Аль-Баас, Хомс, Сирия.
Мухаммад Башар Мойни
Профессор кафедры Механическая энергетика Механического факультета
Инженерия, Университет Аль-Баас, Хомс
Салах Аль-Шамали:
доцент кафедры механической энергетики механического факультета Инженерия, Университет Аль-Баас, Хомс
Акл Мандоу:
доцент кафедры механической энергетики механического факультета Инженерия, Университет Аль-Баас, Хомс

МОДЕЛИРОВАНИЕ ЛОПАТКИ ГАЗОВОЙ ТУРБИНЫ С ПОМОЩЬЮ ОБРАТНОГО ПРОЕКТИРОВАНИЯ

Аннотация: *Газовые турбины играют важную роль на электростанциях. Основная функция лопаток в газовых турбинах заключается в передаче или извлечении энергии. Поскольку основная функция лопастей заключается в плавном изменении скорости потока жидкости, они обычно состоят из поверхностных узоров, вырезанных настолько точно и настолько сложно, что создание модели обычными методами не рекомендуется, и полученный узор будет непрактичным.*

В случае отсутствия проектных данных процесс обратного проектирования можно рассматривать как основной инструмент моделирования для доступа к проектной информации. Процесс реверсивного проектирования включает определение геометрии текущей изучаемой детали, которую необходимо спроектировать, создание инженерной модели детали на основе вычисленных данных и передачу этой модели в подходящую систему CAD/CAM для производства. Это исследование в основном касается моделирования лопаток газовых турбин. Данные конструкции лопатки турбины получены с использованием метода реверс-инжиниринга. По полученным данным создается модель лопаток турбины в SolidWorks с помощью лазерного 3D-сканера.

Ключевые слова: *реверс-инжиниринг, лопатка газовой турбины, первая ступень, моделирование, лопатка.*

1-Introduction:

Reverse engineering is a tool concerned with discovering the technical principles of a particular machine or system by analyzing its structure, function, and mode of operation.

Unlike traditional engineering, which begins by describing what the part will do and produces an engineering model suitable for its manufacture. reverse engineering begins with the manufactured part and produces an engineering model for it.

A wide interpretation of the term "reverse engineering" might involve inferring the original designer's intent to some extent. [1].

Reverse engineering of a blade is also widely recognized as a critical step in the product design cycle. Reconstruction of the blade surface is an iterative process of developing mathematical models from existing physical objects for finite element analysis (FEA), computational fluid dynamics (CFD), and rapid prototyping in order to reduce product design time [2].

In the present study, a method of modelling a gas turbine blade will be described in order to create a model identical to the original model through the technique of reverse engineering.

Due to the complexity of the shape and design of turbine blades, the resulting model is often not practical in conventional methods. A simple change in blade geometry can make a huge difference in the performance of turbines. Therefore, controlling blade shape is critical to the design process.

In this paper, a computational reverse engineering technique will be tested to build models that are identical to the original model

2-Research Objective and its importance:

Turbine blades are the most important part of the turbine, the first stage of the fixed and moving blades of the turbine are the most parts or components that suffer from high temperatures and high stresses. The blades constitute the largest size of the turbine, approximately 65% of the turbine in total, Therefore, attention to blade design is a priority to achieve a high turbine efficiency and a longer turbine life.

This research aims to reach a successful engineering of the turbine blade that achieves an increase in the efficiency of the gas turbine and thus a longer life through the following points:

1- Determine the blade model data using a 3D laser scanner.

2- Creating a 3D computer model of the moving gas first stage blade in the Jandar thermal station with the help of CAD and SolidWorks based on its realistic specifications.

3- Developing the model to be ready for evaluation through CFD analysis and FEA analysis to get the optimal design.

1- Materials and methods:

3-1- Blade data:

The process of reverse engineering is specific to the object being implemented, however, regardless of the context, there are three general steps that are common and important to reverse engineering [3]

- Data extraction:

The first step is to study the object being reverse engineered. Information about its design is extracted and this information is tested to determine how it fits together in reverse engineering. It may require gathering relevant design sources and documents for the study. It may also include the use of tools, packaged software, literature studies and design documents, if any.

This step may also require taking some steps to access the original information without errors.

- Modelling:

After completing the information extraction, the collected information is summarized in a model with each part of the model explaining its function in the overall structure. The purpose of this step is to take the information about the original model and abstract it into a general form that can be used to guide the design of new objects or systems to be worked on later.

- Feedback processes:

After completing the modelling, we begin to review the model and test it in different scenarios to ensure that it is a realistic similar to the original object or system or not.

3-2 Sample preparation for the reverse engineering procedure:

3-2-1 The studied blade and turbine information:

The research sample was chosen and the gas turbine blade was adopted in the Gender thermal plant to study all the effects on a real model in order to reach the real benefit from this research.

Figure /1/ expansion stage at gas turbine.

The estimated life of a first-stage moving blade is 40,000 hours, which equates to 4.5 years

Number of blades in the first stage: 103 blades per turbine.

The turbine consists of 4 expansion stages and 19 compression stages. The following figure shows the four expansion stages in the turbine.

Figure /1/ shows the expansion stages of the selected turbine, where the selected blade of the first stage blades of smaller size shown in Figure /1/ is positioned from.

3-2-2 Sandblasting:

Cleaning is particularly important for alloys because it gives sealing surfaces and increases the life of the alloy.

This process is used to remove dirt, dust, oil, grease, corrosion and surface oxidation from metal alloys so that they appear corrosion-free surfaces.

Figure /2/ shows the studied blade, where thermal and chemical corrosion and rust appear on its surfaces.

Figure /2/ blade before blasting.

There are three general alloy cleaning categories [4] used for all industrial or professional cleaning services:

• Mechanical techniques: abrasive methods such as blasting methods or non-abrasive methods such as ultrasonic.

• Thermal techniques: reactive heat treatments that use temperatures above 100 ˚C or non-reactive treatments with lower temperatures.

• Chemical techniques: reactive methods such as electrical polishing and non-reactive methods such as organic solvents.

While each of these categories has its own applications, mechanical abrasive cleaning methods are the best option for most metal parts.

Blasting methods push different types of abrasive media like sand, silica granules, or even dry ice, against the work piece at high speeds to reduced and completely remove of contaminants from the surface, so blast cleaning is very effective because it can effectively remove contaminants from metal surfaces without damaging the base metal, it can also be used for complicated designs.

Figure /3/ blade cleaning with sand. blastina

Sandblasting also offers unique benefits that water can't do, one of the main results of sandblasting is that it gives surfaces a slightly textured appearance and does not damage metal or details.

Figure /3/ shows the effective cleaning process that the blade was subjected to as it was sand blasted with high temperatures of (80-90) °C.

Figure /4/ shows the results of the mechanical abrasive cleaning process using sand media. The surfaces appear free of dirt, rust, and chemical and mechanical corrosion, so they are ready for the second step, which is the 3D scanning.

Figure /4/ blade surfaces after handling process.

3-3 scanning device:

Computer-aided design [3] (CAD) is a reverse engineering technique used to recreate a manufactured part when the original scheme is not available, involving the production of 3D images of the part so that it can be re-manufactured. A coordinate measuring machine measures the part, and as it is measured, a 3D wireframe image is created using CAD software and displayed on the screen.

The first step in computer-aided design is represented by 3D laser scanning, which is the most common and used 3D scanning technology, where the shape of the object is captured digitally using laser light to obtain a digital representation of the real object. These 3D scanners are able to measure fine details and capture free shapes to create High resolution pixel clouds.

This laser scanning technology is ideal for measuring and examining complex geometric shapes and allows obtaining measurements and data in an effective way that cannot be achieved by traditional methods.

A scanner that uses laser light is a bit like a camera: it can only capture what's in its field of view. In this process, a laser point or line is projected onto an object from the device and a sensor measures the distance to the surface of that object.

Figure/ 5/ 3D scanner.

By processing this data, it can be converted into triangular mesh and point clouds on CAD software.

The code chosen in this research was scanned using a 3D laser scanning device with the following specifications:

Creality CR-Scan 01 3D scanner shown in Figure /5/.

• Scanning distance (40-90) cm - working range (30-50) cm.
• Scan accuracy (0.2-0.5) mm - (10-16) frames per second.
• Precision 0.1 mm.

4-Results and discussion:

4-1 Obtaining a 3D computer model of the blade:

The 3D scanning process is divided into several steps:

The first step is to select the object to be scanned and to select the appropriate position to perform the scan process (fixed position - rotating disk), the second step is to perform the scanning process of the part to be scanned, and the third step is the process where processing refers to efforts to “clean up” the scan data and repair it. often Examination contains unwanted content or areas that need more details which is done within this stage.

and the final step of the scan is to export a 3D mesh model that includes the entire shape with the smallest details, where it is exported in several formats including (STL, OBJ) and then the shape is ready to be modeled.

The modelling process is done with the help of a CAD program, where the file is exported to the CAD programs, and the program identifies the file as (Graphics or Mesh). In this research, the SolidWorks program was used to complete the modelling process, and the body was identified as a black cloud of points (Mesh).

The first stage of modelling is by identifying the program with the file that was exported to it and identifying the cloud as shown in Figure 6 and 7, and then defining reference plane from which to start with the complete redesign.

The second stage is by dividing the work on the shape so that in this article the work was divided on the body of the blade first and then work on the root of the blade, where a reference plane for the body of the blade was taken by taking three points as shown in Figure No. 8 and then work was done by taking multiple sections of the body of the blade To determine the change in the blade profile and to determine the torsion coordinates, 8 segments were taken along the blade body as shown in Figure /11/ and /9/.

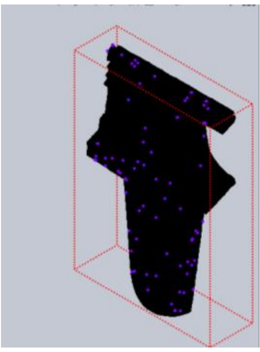


Figure /7/ blade body as clouds.

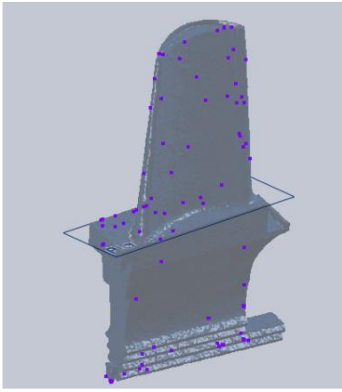


Figure /8/ references planes.

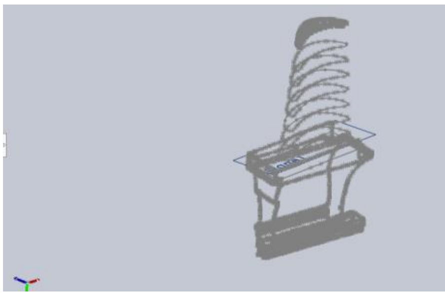


Figure /9/ blade body.

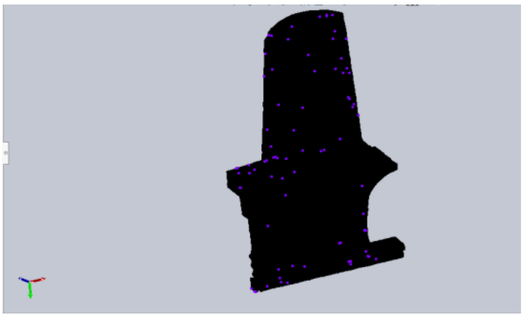


Figure /6/ Mesh.

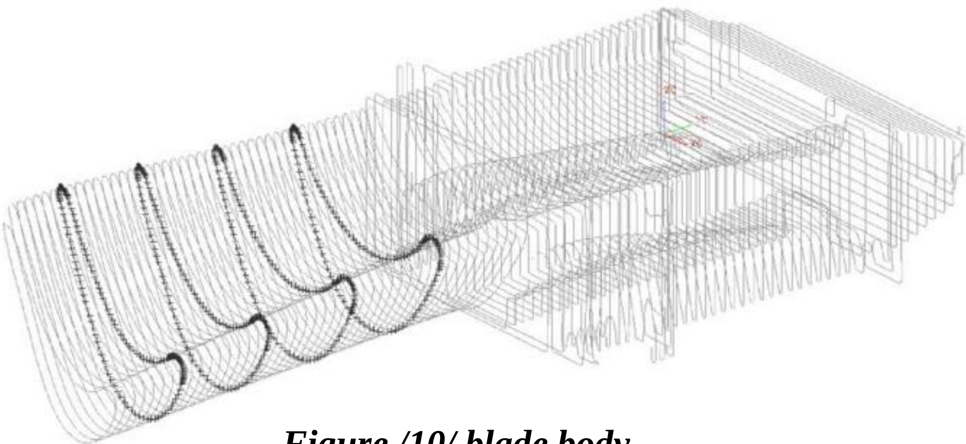


Figure /10/ blade body.

After selecting an appropriate number of segments and selecting the appropriate plane, the CAD program commands are used to build the body of the blade. Figure /10/ shows the body of the blade after connecting all the sections and reaching this final output.

Using the same approach and method, work is done on the root of the blade using planes and sections, and the final stage is to work on the cooling passage holes as shown in Figure /12/, and then reach the final model as shown in Figure /13/.

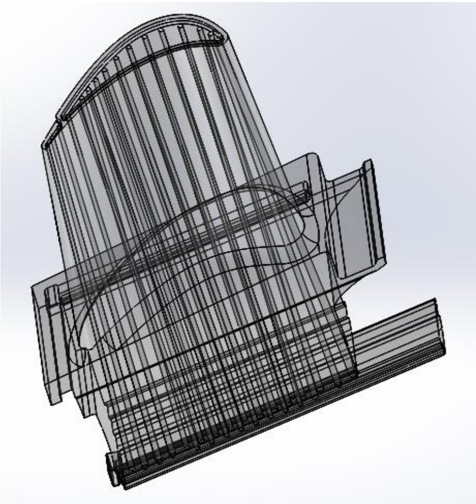


Figure /12/ cooling passing.

Figure /13/ final model of blade.

4-2 Blade dimensions and details:

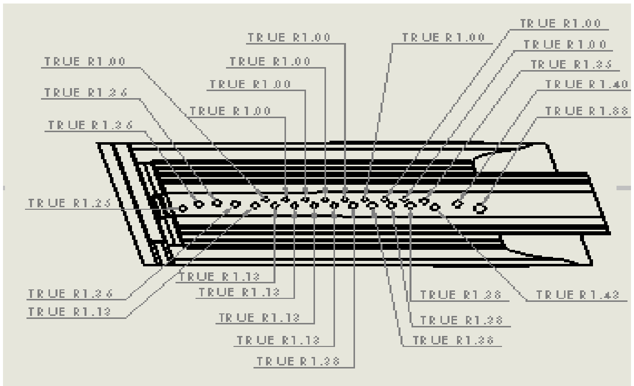


Figure /14/ cooling passing.

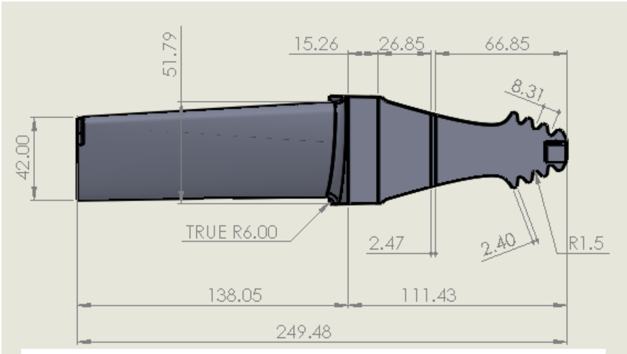


Figure /15/ right plane of blade.

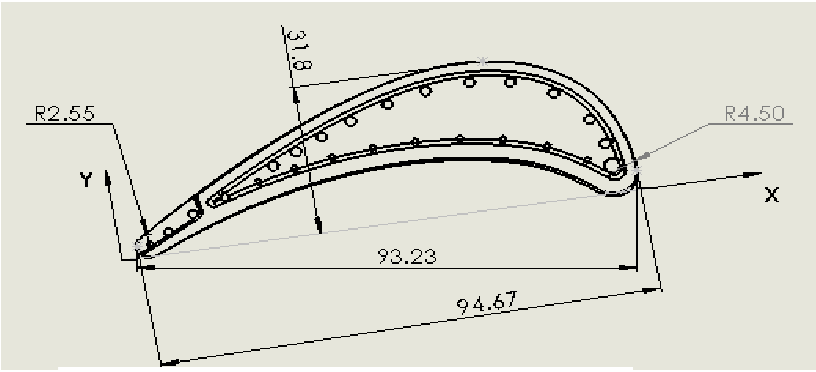


Figure /16/ blade profile.

The blade profile was verified and compared with the blade profile in the Russian atlas concerned with the profile of gas turbine blades. Figure /17/ shows profile number P-5033A corresponding to the studied blade profile, where the ratios of the blade diameter to the distance were taken from the highest point in the back of the blade to the lowest distance in the belly of the blade.

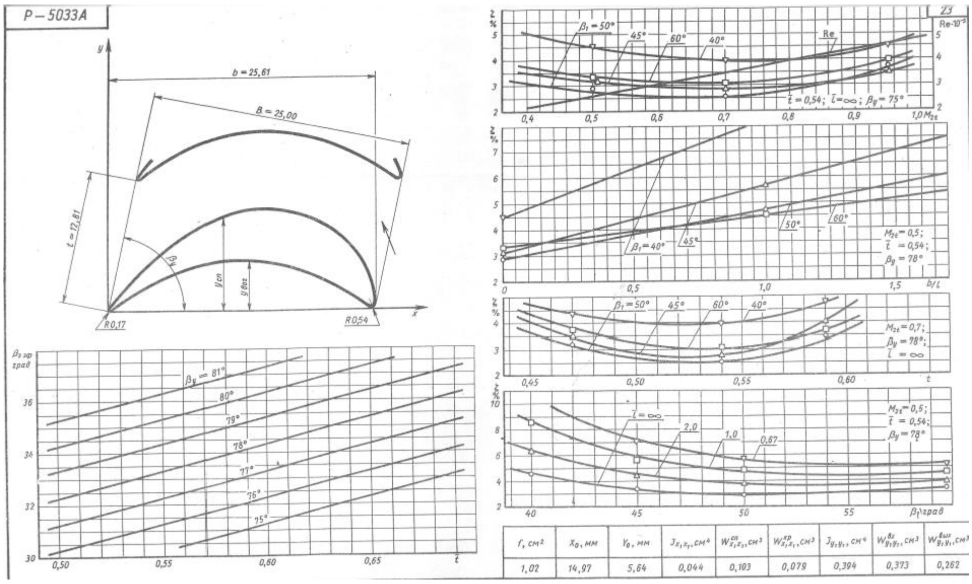


Figure /17/ profile No. P-5033A.

4-3 Blade spectroscopy analyses:

Chemical analysis methods [5] depend on measuring the wavelength and intensity of electromagnetic radiation where its main use is to determine the arrangement of atoms and electrons in molecules of chemical compounds on the basis of the amounts of energy absorbed during the changes in the structure of molecules or its motion.

Two methods are usually involved:

(1) Ultraviolet (invisible) emission spectroscopy.

(2) Measurement of ultraviolet, visible and infrared spectrophotometers.

In emission spectroscopy, atoms are excited to energy levels above their natural lowest levels (ground states) by electrical discharges (arcs, sparks) or flames. Determining the elements composition of an unknown substance depends on the fact that when excited atoms return to lower energy states, they emit light with distinct frequencies.

The process consists of four connected steps [7]:

1) evaporation of the sample.
2) The electronic excitation of its atoms or ions
3) Dispersion of emitted or absorbed radiation into its component frequencies.
4) Measure the intensity of radiation.

Figure /18/ shows the spectral analyzer.

Figure /18/ spectrophotometers.

The elements involved in the composition of the blade metal have been analyzed by two methods:

1- Chemical analyses:

C	S	Mn	Cr	Ni	Co	Ma	Fe	W
0.06	0.002	0.02	17	60.5	16	5.7	0.28	0

2- blade spectroscopy analyses:

Ni	Ma	Cr	Mo	Cu	Fe	Co	Ti	Al	Nb	W
59.7	0.031	16.3	6.01	<0.001	0.145	12.3	3.27	1.9	0.038	0.007

Si	V	C	P	S	Sn	Mg	Ta	Zr	B	Pb
0.11	0,001	0.117	0.012	0.006	0.005	0.002	0.005	0.030	0.009	0.002

Table /1/ alloys element of Inconel 100/ Udimet 700).

Chemical compositions of investigated alloys										
superalloy	Elements content, % mass									
	Ni	Cr	Co	Mo	Al	Ti	C	B	Zr	Nb
Inconel 713LC	74	12.5	-	4.2	6.1	0.8	0.05	0.012	0.1	2
Inconel 100	60	10	15	3	5.5	4.7	0.18	0.014	0.06	-
Udimet 700	58	14.6	15	4.2	4.3	3.3	0.07	0.016	0.04	-

Returning to the results of the spectral analysis and comparing them with the tables of metal alloys, we note that the result of the analysis is consistent with [6] the alloys of Inconel 100 / Udimet 700 shown in Table No. /1/.

Table /2/ thermal property of Udimet 700)

Thermal diffusinity, thermal conductivity and specific heat of superalloy In 100 as a function of temperature			
Superalloy Udimet 700 – density : 7.988 g/cm ^{3}			
Temperature ˚C	Thermal diffusinity, mm^2/s	Specific heat J/(g.K)	Thermal conductivity, W/(m.K)
760	4.232	0.601	20.317
872	4.200	0.610	20.465
980	4.283	0.633	21.657
1090	4.610	0.660	24.304
1178	4.638	0.668	24.748
1248	4.415	0.668	23.558

By researching [6] the thermal properties of these alloys as shown in Table No. /2/ and Table No. /3/, we find that these alloys are suitable for the study turbine working environment, where nickel-based super alloys are primarily used in aircraft engine turbines, marine and energy industries.

The operating temperature of these materials ranges from approximately 150 ˚C to 1500 ˚C.

Thermal conductivity is an important physical property of materials that enables the evaluation of the usefulness of a metallic material for high-temperature structural applications.

Table /3/ thermal property of Inconel 100

Thermal diffusinity, thermal conductivity and specific heat of superalloy In 100 as a function of temperature			
Superalloy In 100 – density : 7.910 g/cm^3			
Temperature ˚C	Thermal diffusinity, mm^2/s	Specific heat J/(g.K)	Thermal conductivity, W/(m.K)
18	2.613	0.440	9.094
98	2.891	0.467	10.679
199	3.154	0.489	12.200
299	3.410	0.503	13.567
401	3.729	0.517	15.250
500	3.977	0.528	16.610
599	4.269	0.588	19.855
701	4.637	0.592	21.714
799	4.649	0.606	22.285
898	4.738	0.615	23.049
998	4.932	0.637	24.851
1097	5.045	0.662	26.418
1197	5.232	0.668	27.645

4-3 Verification and validation:

Developing rigorously validated and automated methodologies to unravel the complexity of engineered molecular networks remains a major challenge. When the experimental and analytical requirements are needed, there is a great deal of diversity in reverse engineering methods, making independent validation and comparison of their predictive capabilities challenging.

In this work, experimental verification method related to adding the type of alloy to the CAD programs is presented, so that the real weight of the real blade can be compared with the weight of the physical model that was built by the reverse engineering method.

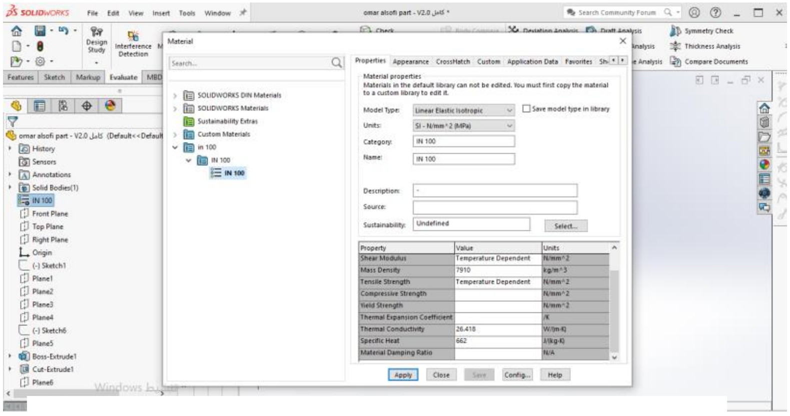


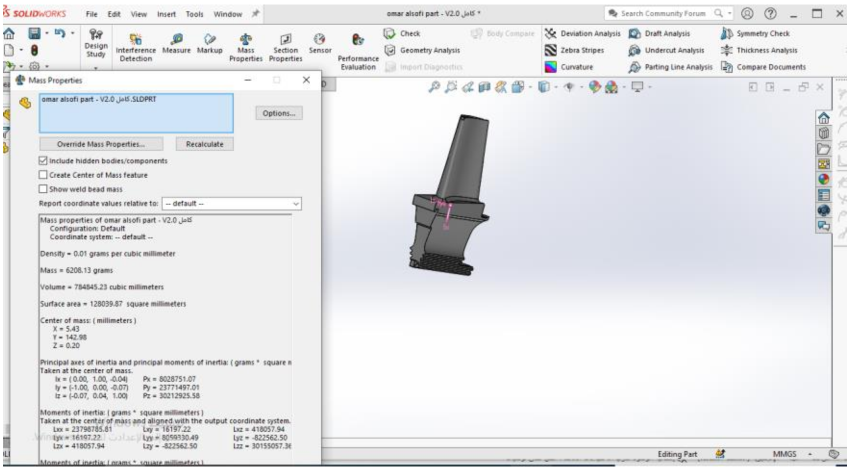
Figure /19/ adding metal property.

All information about the alloy Inconel 100 [6] as density of the material, thermal conductivity and all the information was taken and then added to the hypothetical model shown in Figure /19/, and then the weight of the hypothetical final metal was taken as shown in Figure 20-21, and then the real blade was weighed for comparison as follows:

• It is noted that the weight of the blade on the program equals 6.208 kg

• It is noted that its real weight equals 6kg

• The matching percentage through weight is 96.64%.



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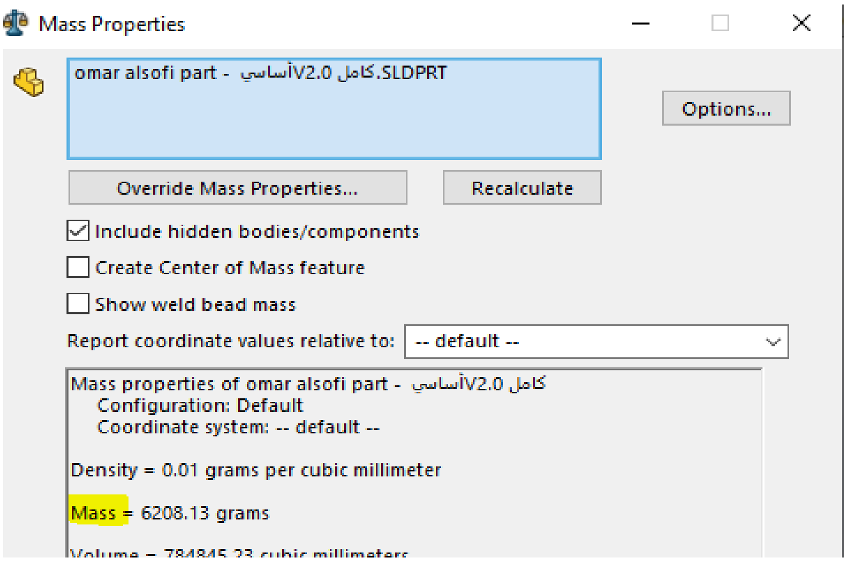

Figure /21/ blade weight.

5 conclusions:

This research used a combination of Reverse Engineering (RE) technology to first generate a solid model of a gas turbine blade in SolidWorks, and the study shows the following results:

1. The proposed reverse engineering approach can be successfully applied in reconstructing a CAD model from product prototypes, to achieve a rapid digitization process that maintains high accuracy.
2. Understanding the physical model and the function that the model performs before starting reverse engineering helps a lot in increasing the accuracy of the results obtained.
3. The metals used in the alloys meet the operation conditions and the spectral analysis method is accurate and successfully helps in increasing the accuracy of the results in reverse engineering.

Moreover, the result of gas turbine blade reconstructed enables us to use complete CAD models to manufacture similar blades with high accuracy up to 97%.

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