Development of Low-Cost Tesla Transformer for High Performance Testing 115 kV Line Post Insulator

B. Plangklang, P. Apiratikul , K. Phumkittipich

Abstract

Nowadays, a high voltage with high frequency Tesla transformer is used for testing a 115 kV line post insulator. However, the cost of Tesla transformer is still high therefore this paper presents the design, and construction of a low-cost high performance Tesla transformer for line post insulator testing. Since the designed Tesla transformer is for line post insulator thus the output of the transformer is designed for rate of 500 kV. The output wave shape is controlled based on the resonance circuit. The simulation and experimental results of Tesla transformer is presented the suitability of the principle design parameters. From the test results, it is found that the performance of the output obtained from the Tesla transformer is satisfied to test a line post insulator.

***Key Words*-Tesla Transformer, resonance frequency, line port insulator.**

I. INTRODUCTION

Tesla Transformer is a high voltage and high frequency transformer based on a resonance circuit [1]. In view of quality requirements for line post insulator, a wide range of quality assurance techniques is applied. High frequency testing is one of the most effective destructive tests for screening and rejecting poor quality line post insulator. Therefore, high frequency and high voltage supplies are required for the insulation tests. In power transmission system, there are varieties of insulator producing companies which require a Tesla Transformer for testing their insulator. A line Post insulator is one of their products which are produced for 115 kV electrical transmission line supporting as shown in Fig. 1. This paper presents the design, and construction of a low-cost high performance Tesla transformer for line post insulator testing. The prototype has all very low cost components. It has been tested and used to test the line post insulator according to TIS. 354-2523 (Thai Industrial Standard) [2]. It is found that the performance of the output obtained from the Tesla transformer is satisfied. It has more than 2 meters long of flashing

Rest of this paper is organized as follows. Section II presents the line post insulator. The design procedure is discussed in section III. Section IV presents the testing of Tesla transformer. The conclusions are given in the last section.

II. LINE POST INSULATOR

A line post insulator is one of the most effective supporting insulators for transmission power line. In Thailand, the 115 kV transmission power line is used this post line insulator for supporting the power line, Figure 1 shows a schematic model of a line post insulator. It is made by porcelain and has to be tested according to a standard.

It has a very long leakage distance therefore it can support a very high voltage.

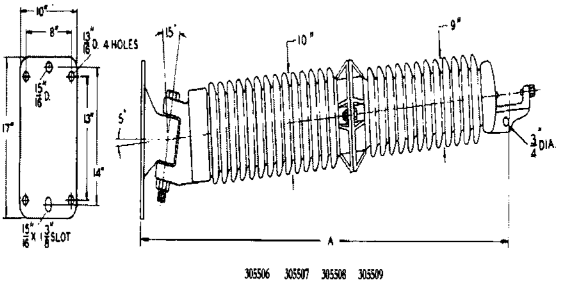

Figure 1: A model of a line post insulator.

In order to make a quality line post insulator, High frequency testing is one of the most effective destructive tests for screening and rejecting poor quality line post insulator. With high frequency testing, the physical property of the line post insulator is observed, therefore the Tesla transformer is designed and constructed for this purpose.

III. Design Procedures

The designed circuit diagram of the constructed Tesla transformer is shown as Figure 2. The primary winding (L_1) and the secondary winding (L_2) of the transformer are linked using the air core. The spark gap (SG) is a single phase motor driving a switching device. On closing the gap, the current can flow in the primary winding, and this can induce the high frequency oscillation in the secondary winding. The frequency of the output wave shape can be controlled using Equation 1 [1].

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}} \qquad (1)$$

where,

f = the oscillation frequency of an output wave shape

L_1 = the inductance of the primary winding

C_1 = the capacitance at the primary side.

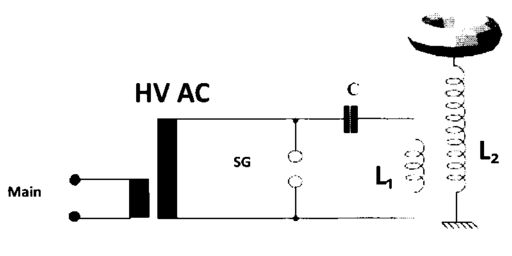

Figure 2: A circuit diagram for a designed Tesla transformer.

In order to design a Tesla transformer, the capacitance at the secondary side of the transformer has to be known. The capacitance consists of the load capacitance, the stray capacitance of the winding, the capacitance of a sphere gap and the capacitance of the electric stress control device. When the output frequency is designated, the inductance of the winding can be determined using Equation 2 [1]:

$$f = \frac{1}{2\pi\sqrt{L_2 C_2}} \qquad (2)$$

where,

f = the oscillation frequency of an output wave shape

L_2 = the inductance of the secondary winding

C_2 = the total capacitance at the secondary side.

According to the formula calculation [1-6], the designed Tesla transformer can be calculated as:

C1 = 60 nF

C_2 = 54 pF

L_1 = 74.2 H

L_2 = 40.9 H

According to the circuit and the designed parameters of the Tesla Transformer, with MATLAB/ Simulink simulation, the output of the Tesla transformer is carried out as in figure 3.

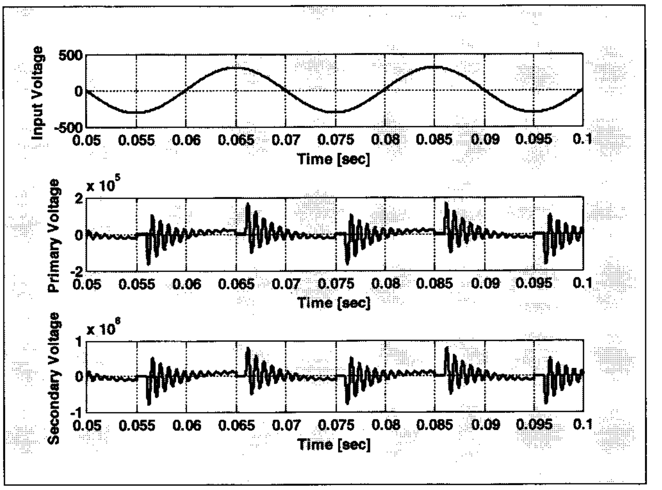

Figure 3: Simulation outputs of a designed Tesla transformer.

If consider only at the output wave form (secondary voltage), it can be realized as in figure 4.

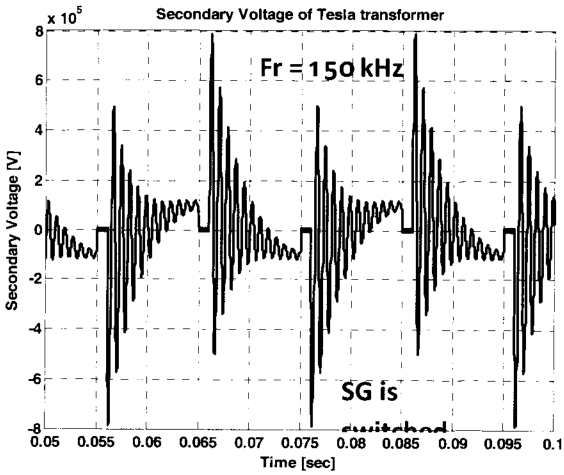

Figure 4: An output of a designed Tesla transformer.

Figure 3a shows the voltage of input transformer that is 220V 50 Hz. The primary voltage of Tesla transformer is presented in Figure 3b with a 150 kHz resonance frequency. Figure 3c shows the output secondary voltage which has a peak voltage about 800 kV. The output is satisfied for testing a line post insulator.

A Tesla transformer is designed in the principle operation of high voltage and high frequency. The components must be considered and chosen with the condition of voltage rated. The thickness of the winging tube used as the L_1 primary winding has to take into account the skin depth effect. The skin depth was calculated at the output frequency (150 kHz). The L_1 winding is made by copper tube with tile angle 15°. This concept is combined the vertical winding concept and horizontal winding concept together. This will make the Tesla coil more effective by the advantages of both concepts. Figure 5 shows the L_1 winding.

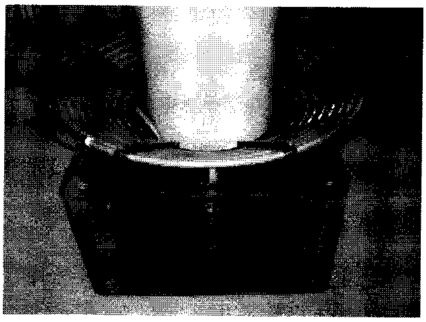

Figure 5: The L_1 primary winding of the Tesla coil.

The L_2 secondary winding is made of an AWG 22 wire. It's wound on the PVC tube. The skin effect of L_2 winding is considered therefore the varnish insulator is covered secondary coil.

The Neon transformer which can produce a high voltage for Neon lamps is used as a source for HV input of L_1 winding. Total 12 Neon transformers are connected to a rate of 220/1500 V and 24 A. The input voltage of Neon transformer delivers 0-220 V. The primary of input transformer has 6 tabs 120, 140, 160, 180, 200, 220 working as an auto transformer. Control relays are used to control an input of the primary tabs of the transformer 0-220 V. Figure 6 shows the control board comprising an input transformer, control relays and Neon transformers.

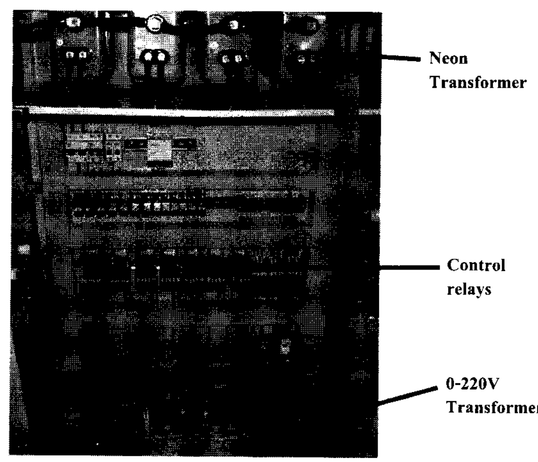

Figure 6: A control board and Neon transformers used as a source.

The capacitor at the primary side of the Tesla transformer was built using sets of Polypropylene capacitors. The voltage rated of capacitor is 3 times of the operation voltage. Total capacitance from the measurement is 60 nF. The capacitor is shown as Figure 7. The output voltage of Tesla Transformer is carried out at the top of L_2 winding this has to design a special toroid. The designed toroid used shown in Figure 10 has a diameter of 60 cm and width 20 cm. The designed toriod induces the C_2 = 54 pF. The toroid has to be clean and smooth shape for uniform electric field.

Figure 7: The C1 capacitor at the primary winding

The SG was constructed using 8 copper spark tubes driving by a 1500 rpm motor. There were 4 gaps in series at a time of sparking. The spark gap is shown in Figure 8. The conductor of SG is made by Tungsten material in order to avoid damage from arcing.

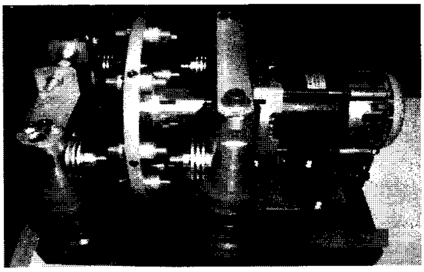

Figure 8: The designed spark gap

IV. Testing of the designed Tesla Transformer

Tesla transformer was assembled as shown in Figure 9. The transformer was designed at a rate of 500kV and 150 kHz as the purpose of line post insulator testing. The objective of the Tesla transformer is to test a porcelain post line insulator employed in a 115 kV transmission line system.

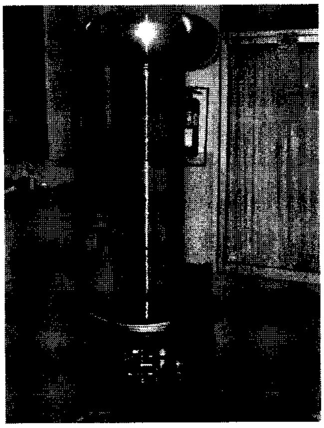

Figure 9: A designed Tesla transformer

From the experiment, the output of designed Tesla Transformer is shown as in Figure 10. The output has 242 kHz and about 800 kVp this can prove that the Tesla transformer is working as the designed and can be used for the post line insulator.

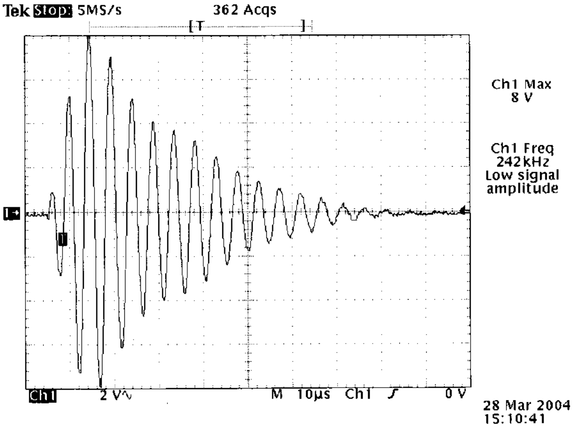

Figure 10: Output of the designed Tesla transformer

Figure 11 shows a test bench of a 115 kV line post insulator. Tesla transformer has more than 2 meters long of flashing. The flashing can break the leakage distance of the line post insulator. This test can provide very useful consideration for testing the insulator. From the experiment, by using local material for construction Tesla transformer, the designed Tesla transformer has lower cost and it can satisfy the breakdown test of the line post insulator.

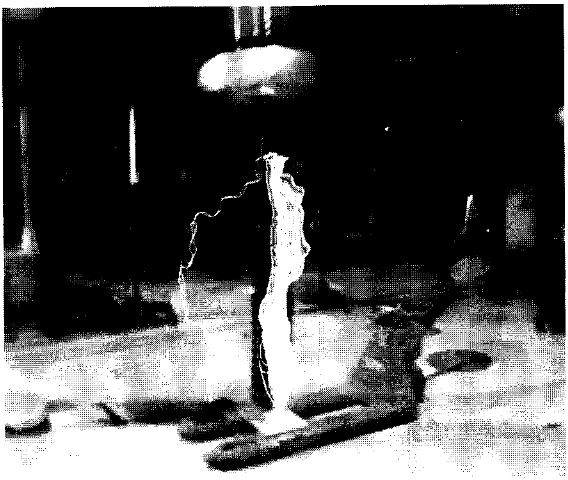

Figure 11: Testing of 115 kV line post insulator

V. CONCLUSIONS

A study of Tesla transformer is done by typical mathematical equations then using simulation method to verify the designed parameters. Accordingly to the simulation results, a Tesla transformer has been constructed and assembled. All components used in the transformer are available from local suppliers in Thailand. Neon transformers are used as a source for HV input L_1 winding of the Tesla transformer. The Tesla transformer has been implemented to test a 115 kV porcelain line post insulator. The designed Tesla transformer is then implemented at RMUTT high-voltage laboratory. The output of the designed Tesla transformer has 242 kHZ with 800 kVp. It has been found that it can satisfy the physical breakdown test of the line post insulator, it has more than two meters long of flashing. From this result, it can prove that the designed Tesla transformer by using local material can be used for the purpose of line post insulator testing. Further work will be the improvement of the design of testing method, the analysis of equivalent circuits determining of exact values for inductances and capacitances.

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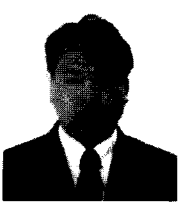
VIII. Biography

Boonyang Plangklang received his Bachelor degree of Engineering (B.Eng) in Electrical Engineering from Rajamangala Institute of Technology, Thailand, in 1996. He received a diploma in Instrumentation at Northern Alberta Institute of Technology (NAIT), Edmonton, Alberta, Canada, in 1997. He graduated Master of Science in Electronics System and Engineering Management at University of Paderborn, division Soest, Germany, with the cooperation of Bolton Institute of Higher Education, UK, by the DAAD scholarship in 2001. He received the degree of Dr.-Ing. in Electrical Engineering from Kassel University, Germany in 2005. He is now working at the Department of Electrical Engineering, Rajamangala University of Technology Thanyaburi (RMUTT), Thanyaburi, Phatumthani, Thailand 12110, Tel. +66 (0) 2549 3429, Fax.+66 (0) 2549 3422.



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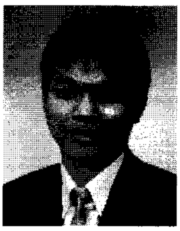

Electrical Engineering from Rajamangala University of Technology Thanyaburi (RMUTT) in 1997, and M.Eng from Chulalongkorn University in 2000, He got PhD. from AIT, Thailand in 2008. He has worked as lecturer at the Department of Electrical Power Engineering of RMUTT since June 1997. In November 2001-December 2003, he worked as research associate at Institut fuer Stromrichtertechnik und Elektrische Antriebe, Rheinisch-Westfaelische Technische Hochschule Aachen, Germany. His main research interests are applications of FACTS Controllers, Power Quality Monitoring, Power Electronic System and Optimization Techniques.

Numerical Solution for Three Dimensional Nesting using Hybrid Genetic Algorithm

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Abstract

This article seeks a numerical method to improve the efficiencies of three-dimensional objects placement by minimizing multiple-objects arrangement sequence and maximizing the utilization of the space in the three-dimensional specified work volume. The approach applied a heuristic algorithm or Home-seek algorithm with a regular genetic algorithm. The Home-Seek algorithm is used to sequentially place all objects in the specified volume in order to minimize both the wasted space and the number of occupied work spaces. The genetic algorithm is used to generate the sequences of objects under consideration and placement of those objects in order to find a sequence with the best properties for optimized result. After the approach established, the computer simulation codes were written according to the objective and the proposed method. The simulations show that the working volume is truly optimized according to the numerical approach.

Keywords: three dimensional nesting, heuristic algorithm, and genetic algorithm

1. Introduction

Numerical methods are widely used to solve several engineering problems. In many case, a combination of two or more methods have been used for better efficiency. The nesting problem is one of the most difficult problems to be solved because its nature is involved with multiple degrees of uncertainties. Therefore, a new numerical method or an applied numerical method is needed for solving this kind of trouble. The hybrid of the existence methods is a good choice for this matter. The hybrid approach in this article, which is combined of both the genetic algorithm and the heuristic algorithm, is proposed for nesting of different three-dimensional objects in a single three-dimensional working volume. The objectives are to effectively utilize the three-dimensional space in the case of a single working volume with minimum wasted space. The proposed genetic approach gives the best sequence of objects placement into the selected working volume to generate an effective nested pattern with a heuristic algorithm. Then, the heuristic approach is used to arrange each of the parts onto the "closest to home" position of the selected envelope by considering the sequence of parts given by the previous genetic algorithm. This procedure repeats within the simulation until the system reaches the certain limiting target value or there is no more improvement in the results.

2. Previous Investigations

Heckman and Lengauer [1] used simulated annealing algorithm to solve a wide variety of constraints in nesting problem. In Lamousin and Waggenspack's [4] research, they used the shape reasoning heuristic approach to solve the two-dimensional nesting problem. In Hopper and Turton's [2] research, the researchers proposed two hybrid genetic algorithms for the rectangle packing problem. The first technique is the Bottom-Left heuristic algorithm, and the second one is an improved version called 'Bottom-Left-Filled' heuristic algorithm. A. Ramesh Babu and N. Ramesh Babu [5] used a hybrid approach, which employs both genetic algorithms and heuristic algorithms, to nesting of different rectangular parts in multiple rectangular sheets. As in their previous research A. Ramesh Babu and N. Ramesh Babu [6] used a hybrid approach of a genetic and heuristic (the bottom-left) approach for the nesting of multiple two-dimensional shaped parts in multiple two-dimensional shaped sheets.

3. Engineering Backgrounds

3.1 Genetic Algorithm

The genetic algorithm was invented by Holland [3]. This algorithm is meant to solve the non-linear multi modal functions. Genetic algorithms work with a group of possible solutions (strings) and do not need to use much directly knowledge about the problem to be solved. In this method, all of the strings will put through some several steps. They are string coding, initial population, fitness function, reproduction, crossover and mutation.

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3.2 Object Nesting

The nesting process is the procedure of parts or shapes arrangement under some specific constrains, such as, area, wasted materials. Normally, the procedure uses suitable search method, heuristic method, or a combination of both methods. These selected methods are used to search a good sequence of the set of parts or objects with a good result in the utilization of the working space or materials.

4. Numerical Simulation Procedure

4.1 Coding for each string

Each particular size of three dimensional objects is assigned. Each object identification number can be assigned randomly or any integer but assigning in the plain order is of more convenience for programming. Each string or placement sequence is then composed of these part identification numbers. The length of each string must be equal to the total part quantity

4.2 Initial population

Normally, size of the search space is very big according to number of possibilities. Since the three-dimensional objects are involved, the searching for the optimal solution has more complexity. The possible chance to reach the optimal solution is shown in Equation (1).

$$S_f = R^n \tag{1}$$

where S_f is the possible number of the feasible solutions, R is the possible number of each part orientation, and n is the number of the total parts.

4.3 Applied Heuristic algorithm

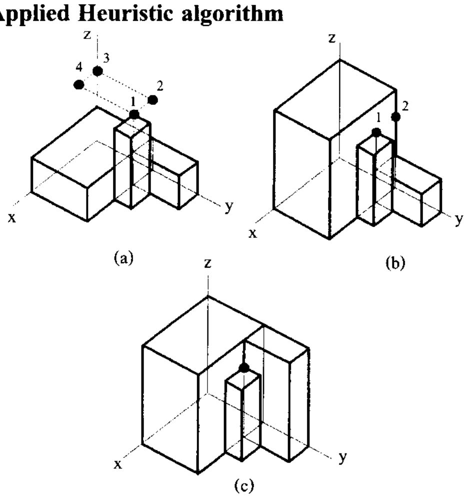

Figure 1 The creation of the referenced nodes on several objects-placement cases: a) four feasible nodes, b) two feasible nodes, and c) one feasible node

In this research, the heuristic algorithm called "Home-Seek" algorithm is used to generating a nested pattern from a given string. In Home-Seek algorithm, the nesting starts with placing the first part at the origin or home position of the working space. Then, all the reference nodes have been created. The next part is now placed into the envelope by translating along these referenced nodes. As mentioned, the smallest x displacement node gets the first pick and then y, and z, respectively. Same as the first part placement, each new part placement gives new referenced nodes for the next part. After finish the first string, the next string in the population is also subjected to the same Home-Seek procedure. The overall procedure will be completed after all strings are nested.

4.4 Fitness functions setup and evaluation

After each string is nested as described in the previous section, each nested height and nested volume are known and collected. In this set up, two different digits are used. These digits are height digit and volume digit. The total digit value can be achieved by the following equation

$$D_T = nD_h + D_v \tag{2}$$

where D_T is the total digit, n is the population size, D_h is the height digit, and D_v is the volume digit.

The value of fitness function can be calculated from these total digits by subtracting each total digit with the minimum total digit, as shown in following equation

$$F_i = D_{Ti} - D_{min} \tag{3}$$

where F_i is a fitness function, D_{Ti} is a total digit, and D_{Tmin} is the minimum total digit.

4.5 Reproduction

In this case, the probability of fitness values are used to determine how big of the roulette slot should be. This probability can be calculated from the following equations.

$$P_i = \frac{F_i}{F_{avg}} \tag{4}$$

$$F_{avg} = \frac{\sum_{1}^{n} F_i}{n} \tag{5}$$

where p_i is the probability of the i_{th} string, F_i is the fitness value of the i_{th} string, F_{avg} is the average fitness value of the entire population, and n is the population size. After finishing the count process, each string is submitted to be multiplied process according to its c_i, which is its feasible number, value and then put into the mating pool for the next process.

4.6 Crossover

The crossover operation takes place in the genetic process after all legitimated strings have been put into the mating pool. The crossover operation uses the combination of information between two parental strings.

4.7 Mutation

The mutation process begins with each string in the mating pool and the offspring pool is assigned with a random number. If a particular string has the value of its random number less or equal to the probability number, that string is qualified to be mutated.

4.8 Reevaluation and rejection

After finishing the mutation process, all new strings are considered as a new population and the initial population is now called old population. Every single string from both populations is submitted to calculate for the fitness value. Then all strings are sorted according to its fitness value. Since the population size has to be constant, some strings have to be rejected in order to maintain the size of the population in each generation.

5. Experimental Results

This section presents the results of simulations of the case of single envelope with 120 unit height. The part quantities that had been used in the simulations are 50 parts with 55 unit height.

5.1 Effects of the crossover and mutation chance

Figure 2 shows the results of the several simulations with different preset values of crossover and mutation probabilities. These results are achieved by using trial and error on the values of the crossover and mutation probabilities. The values of probabilities are varied from 0.1 to 0.9 for both crossover and mutation rate. Based on these results, the probability of crossover that range from 0.7 to 0.9 gives good nested heights. According to the best range of probability of crossover, the probability of mutation in the range from 0.2 to 0.5 gives good results. Thus, the

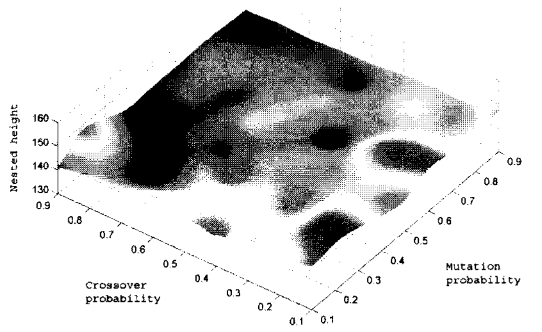

Figure 2 Results relate to the probabilities of crossover and mutation

5.2 Three-dimensional nesting in a specific working envelope

The results show how the strings converged into better quality strings. The second part of this section describes the effects of the part quantity in each simulation. The parts quantity was varied from 10 to 50 objects.

Figure 3 shows the variety of the nested height of every string in each generation. The graph shows a gradually improvement of the nested height as a new generation has been created. Also, the convergence of the nested height is clearly shown as well. Actually, the total numbers of generation are more than that shown in the graph. Also in Figure 4, the graph shows a gradually improvements of the nested volume and wasted volume percentages as a new generation has been created.

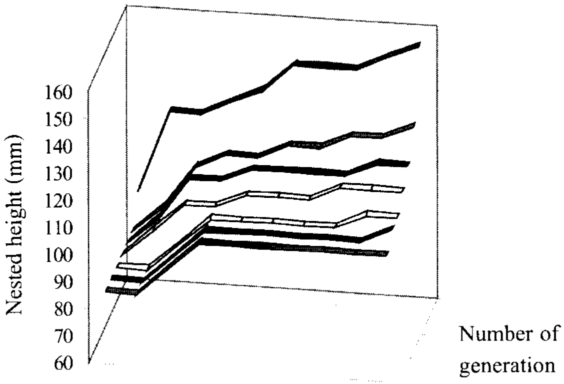

Figure 3 The improvement of the nested height in each generation.

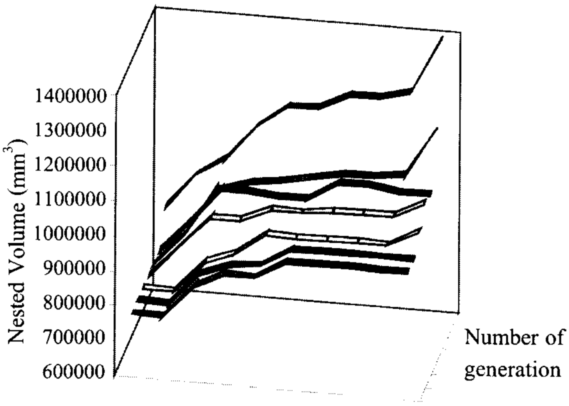

Figure 4 The improvement of the nested volume in each generation.

6. Summary and Conclusion

The setups for different simulations are properly processed according to its restrictions, i.e., size of working volume, and recommended object size. The proper choices of initial condition were also taken into account. Thus, the results show that the improvements of the nested height, the nested volume, and the relative wasted volume percentage happened rapidly in the first few generations. Then, the speed of improvement gradually decreased when the more generations have been born. Finally, the improvement speed reached a sluggish state when the results are in the vicinity of the optimal target. Nevertheless, the simulations show that the working volume is truly optimized according to the numerical approach.

7. Acknowledgement

First, I would like to thank Rajamangala University of Technology Tunyaburi for a lot of opportunities in my research and my job. Secondly, I also want to thank all of my colleagues and my bosses for everything that has helped this work done. Finally, I like to thank all of friends of mine for all of their supports.

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