7th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING"
22-24 April 2010, Tallinn, Estonia

DOUBLE-CURVED SURFACE FORMING PROCESS MODELING

Velsker, T.; Majak, J.; Eerme, M.; Pohlak, M.

Abstract: *The forming process of earth-station antennas reflector panel is studied. The paper is focused on improvement of the accuracy of panels formed in order to meet the increasing quality requirements. The coordinate correction procedure, based on use of response modelling and optimisation, has been developed. The numerical algorithm has been implemented in MATLAB code.*
Key words: satellite antennas, surface forming, response modelling, optimisation.

1. INTRODUCTION

There are several industries where increasingly higher surface accuracy requirements are posed for double-curved surfaces. One industrial application is satellitecommunication earth-station antennas.(see Fig.1)


Fig. 1. 35m diameter antenna [1].

The main goal of the current study is to increase an accuracy of the double-curved surface forming process. The forming method considered below is based on use of the adjustable forming surface which supports reflective surface. Adjustments of the surface are available in fixed set of points and in directions normal to the surface only.

The response surface method (RSM) is employed in order to model relation between input and output data. In the current paper, the generalized regression neural networks (NN) are used for the surface fitting. An approach proposed is based on the use of the MATLAB neural network toolbox.

The deviation of the reflective surface has been minimized by use of hybrid genetic algorithm. Traditional gradient based optimization methods have a trend to converge to the nearest optimum (which may appear to be local), also computation of the first order derivatives of the objective function $f(\bar{x})$ and the constraints function $g(\bar{x})$ with respect to the design variables $\bar{x}$ is necessary. In that reason a genetic algorithm is employed for solving the optimization problem posed. The advantages of the GA over traditional gradient based techniques can be outlined as follows:

- in general, the convergence to global extreme can be expected;
- integer type design parameters can be used;

- computation of derivatives of objective and constraints functions is not required.
-

However, there are also some disadvantages common to GA:

- convergence to the solution close to global optimum (not exactly optimum);
- relatively long computing time.

In order to overcome the above mentioned drawbacks, several refined GA approaches are proposed in literature [2-3] Henz et al. (2007) present a global–local approach for the optimization of injection gate locations in liquid composite molding process simulations [2]. The hybrid approach used provides a global search with the GA and was subsequently further refined with a gradient-based search via the CSE (continuous sensitivity equations). In [3] stochastic hybrid genetic algorithm is developed for survivable resilient networks design. The specialized crossover and local search operators are introduced in the GA algorithm. In Zhu et al. 2007 a novel GA, particularly suited to hardware implementation, is introduced. The optimal individual monogenetic algorithm (OIMGA) is treated, which includes global and local searches that interact in a hierarchical manner.

In [4-6] a similar two layer network was applied by the authors for modeling different engineering problems (design of large composite parts, design of car protection system, modeling new composite material etc.).

2. PROBLEM FORMULATION

In order to achieve the main goal- increase an accuracy of the double-curved surface forming process the procedure for determining the coordinates of the adjustment points has been developed. The two main subtasks of the procedure can be outlines as:

a) deviation measuring in given points,
b) response surface modelling,
c) computing coordinates corresponding to minimal deviation of reflective surface,
d) coordinate correction for adjustment points. (see Fig. 2)

Root mean square (RMS) value is used in order to characterise the precision of the surface. Irrespective of measuring method a certain number of measuring points deviation on the surface is needed for calculating RMS.

In real adjustment process the coordinates in normal directions are considered as input data and the deviations of the reflective surface points as output data (results).

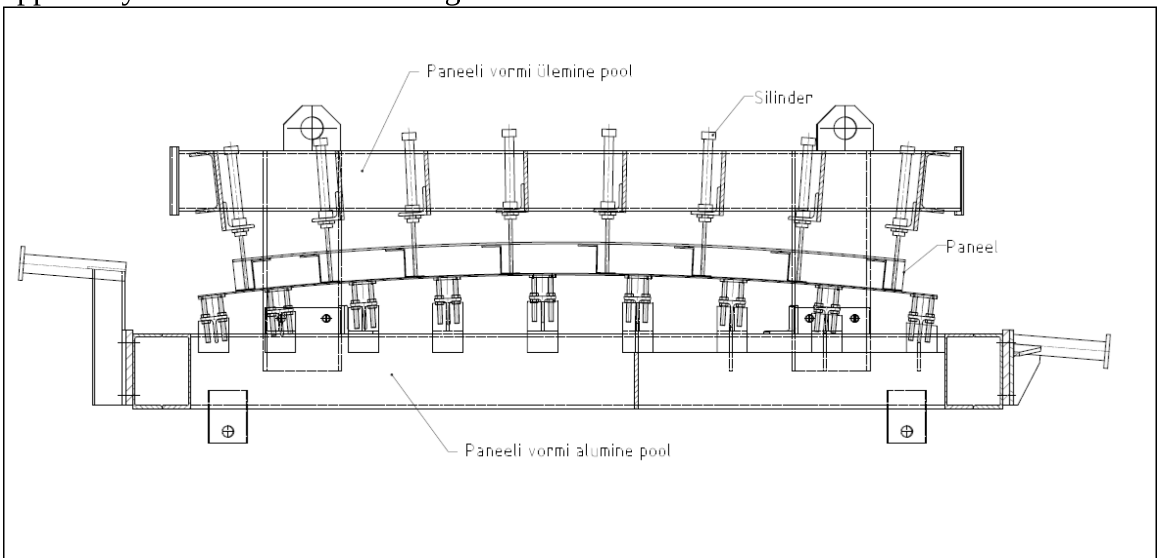

Fig. 2. Forming tool with adjustable surface [7].

3. COORDINATE CORRECTION PROCEDURE

First note, that the coordinate correction procedure is time consuming, since besides numerical algorithm it contains also earth-station antennas reflector panel forming process. The coordinate corrections are necessary for each panel formed until needed accuracy have been reached. However, at the beginning of the forming process of a new type of panel there is not preliminary model data (measurement results) for predicting the coordinates of the adjustment points. First measurement data are obtained after forming first panel of a given type. The corrections done before forming second panel are based on experience of operators, because the response model cannot be built on one input and output dataset. After forming two panels of a given type the dataset is still poor for modelling response between values of the coordinates of adjustment points and deviations of measuring points, but principally the coordinate correction module can be employed. Two main subtasks of the coordinate correction module are the response modelling and optimisation. Detailed scheme of the coordinate corrections procedure is given in Fig.3

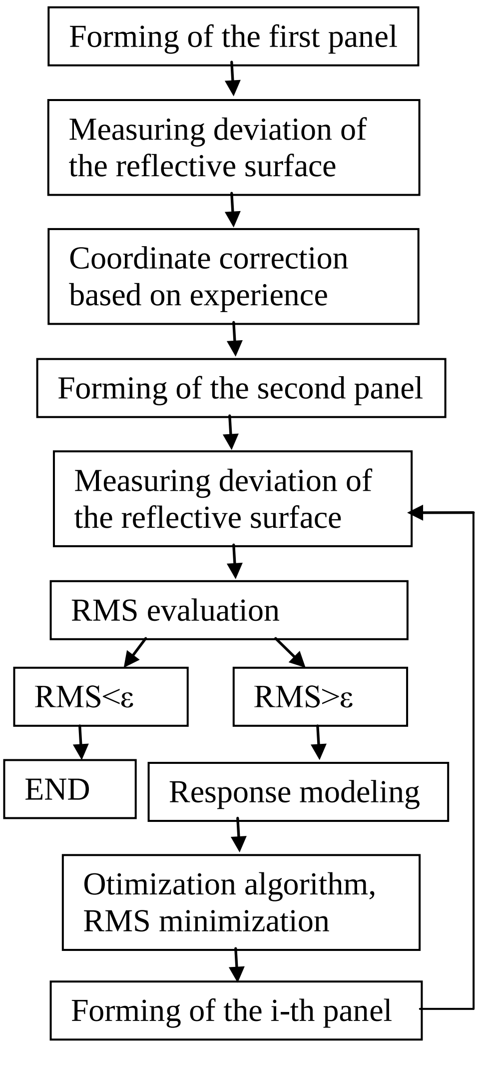

Fig 3. Coordinate corrections procedure

Note that the coordinate corrections less than given constant (0.08 mm) are omitted due to fact that the errors, caused by performing coordinate changes, may exceed the correction value.

Let us assume that after forming n-th panel the required accuracy has been achieved (RMS<ε) and here is no need for coordinate correction. However, the measurement of the deviation of reflective surface and RMS evaluation should be continued in order to guarantee the quality of the product. It may appear that after forming certain number of panels, the accuracy requirement will be violated in some local region or globally (different affectors). In latter case the coordinate correction procedure should by “switched on”.

4. RESPONSE SURFACE MODELING

Using surrogate models for the approximation of the objective and constraint functions is a common technique for reducing computational cost of engineering design problems. In the following, the coordinate corrections for adjustment points are treated as input values and the data obtained from measurement of the deviation of reflective surface are treated as output values. In order to characterize the precision of the surface the root mean square value has been computed (response).

The generalized regression neural networks (NNs) are used for the surface fitting. The surface constructed by the use of NNs does not normally contain the given response values (similarity with the least-squares method in this respect). An approach proposed in this paper is based on the use of the MATLAB neural network toolbox. A two-layer network is generated. General scheme of the multilayer NN can be found in [8]. In Fig. 4 the architecture of two layer NN is given, where $\boldsymbol{p}$, $\boldsymbol{a}$, $\boldsymbol{w}$, $\boldsymbol{b}$ and $\boldsymbol{f}$ stand for input vector, output vector, weight matrix (SxR), bias vector and transfer functions, respectively. The first layer has radbas neurons and the second layer has purelin neurons. The dimensions of the weight matrix S and R are determined by number of elements in input (layer) vector and number of neurons in layer.

The neural network architecture, depicted in Fig. 4, is covered by a quite simple mathematical formula

$$\boldsymbol{a}^2 = \boldsymbol{f}^2[\boldsymbol{LW}^{2,1}\boldsymbol{f}^1(\boldsymbol{IW}^{1,1}\boldsymbol{p} + \boldsymbol{b}^1)], \qquad (1)$$

where $\boldsymbol{IW}^{1,1}$ and $\boldsymbol{LW}^{2,1}$ stand for wieght matrices of the input and second layer, respectively, $\boldsymbol{f}^1$ is a linear and $\boldsymbol{f}^2$ radial bases function. The neural network model, built in MATLAB, can be exported to different computing environments using the relation (1).

In order to calculate outputs for a concurrent set of values of the design variables, a network simulation function **sim** was used.

5. MINIMIZATION OF THE DEVIATION OF REFLECTIVE SURFACE

The root mean square value of the deviations of the parabolic reflective surface of satellite communication earth-station antennas reflectors is subjected to minimization

$$F = \frac{1}{n}\sum_{i=1}^{n}[(z]_i^m - z_i^0)^2 \rightarrow min \qquad (2)$$

where z_i^m and z_i^0 are the values of the coordinates of reflective surface corresponding to measurement results and zero deviation, respectively. As described above, each value of the function F corresponds to one panel formed. Thus, the experimental data, gathered at the beginning of the forming process of new

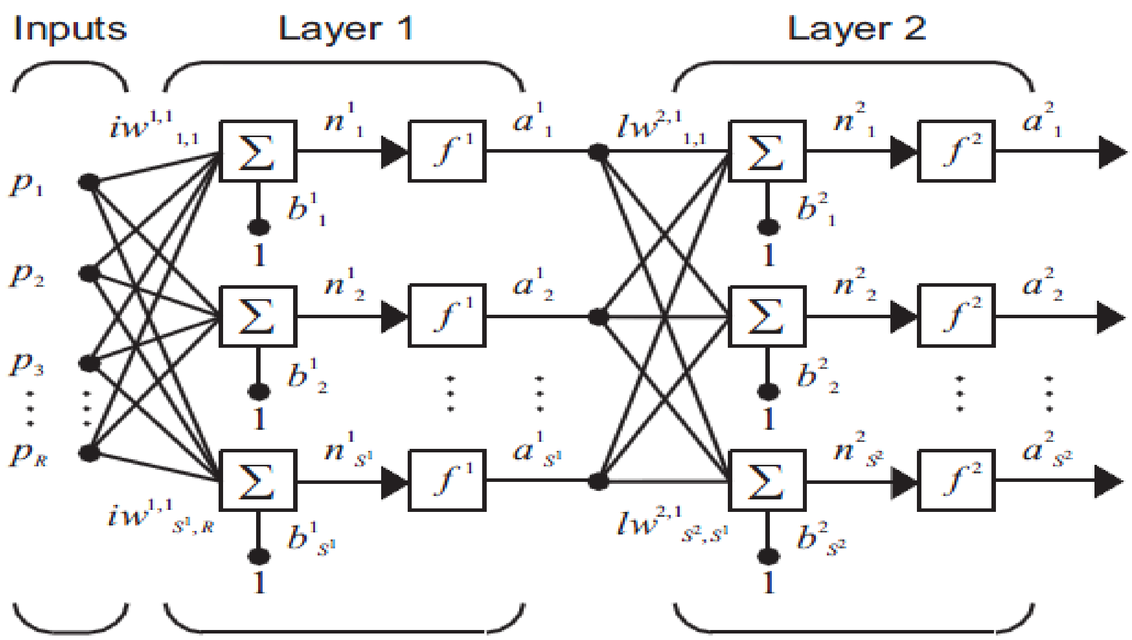

Fig. 4. Architecture of the two layer feedforward neural network.

type of panels is limited and response modeling necessary.

Let us proceed from the surface modeled by the use of neural networks (see section 4). In order to determine the minimal value of the objective function (2) the genetic algorithm has been applied. In order to achieve higher accuracy the real-coded approach of the genetic algorithm is considered. As it can be expected, optimization via genetic algorithms (GA) uses natural selection as a tool of search for the optimal solution in the global domain, the computed solution is not the global extreme, and rather it is a value close to it. Thus, further refinement of the design is still necessary. An approach considered for design improvement herein is employing hybrid GA. This algorithm consists from a global search and one or more local searches. The global search is performed by the GA, but the steepest decent method is applied for the local search using the following domain

$$lb[i] = x_i^g - \delta_i, \quad ub[i] = x_i^g + \delta_i, \quad (i = 1, ..., n), \qquad (3)$$

where x_i^g stands for the value of the design variable obtained from the global search and δ_i is a given deviation for the i – th variable. The hybrid GA converges faster in comparison with GA and results higher accuracy.

6. RESULTS

The deviation of the reflective surface has been minimized. However, the zero deviations are not achieved due to measuring, modeling, etc. errors. Employing the coordinate correction algorithm proposed, allows to reduce the number of experiments performed (panels formed) up to required accuracy has been achieved. The problem considered is specific due to limited dataset for response modeling at the beginning of the new type panel forming.

7. CONCLUSION

The main goal of the current study has been achieved, the accuracy of the double-curved surface forming process has been improved. The artificial neural networks and global optimization techniques are combined for solving the engineering problem posed above.

8. ACKNOWLEDGEMENTS

The work has been supported by Estonian Science Foundation grant G8485

9. REFERENCES

1. Baars W.M , J. The paraboloidal reflector antenna in radio astronimy and communication theory and practice, Springer, 2007.
2. Henz BJ, Mohan RV, Shires D.R. A hybrid global–local approach for optimization of injection gate locations in liquid composite molding process simulations, *Composites: Part A*, 2007, 38, 1932–1946.
3. Konak A, Bartolacci M.R. Designing survivable resilient networks: A stochastic hybrid genetic algorithm approach. *Omega, the International Journal of Management Science* 2007, **35**, 645 – 658.
4. Pohlak M, Majak J, Eerme M. Optimization study of car frontal protection system. *Int. J. for Simulation and Multidisciplinary Design Optimization*, 2007, 1 (1), 31-37.
5. Pohlak, M. Majak, J. Karjust, K. Küttner, R. Multicriteria optimization of large composite parts . Composite Structures, in press..
6. Kers, J. Majak, J. Modelling a new composite from a recycled GFRP.

Mechanics of Composite Materials, 2008, 44(6), 623 - 632.
7. Velsker, T. Paraboolantennide reflektorpaneelid, Tallinn, 2007.
8. Hagan M.T., Demuth H.B., Beale M.H. Neural Network Design, 2002.

10. CORRESPONDING ADDRESS

MsC. Tarmo Velsker
TUT, Department of Machinery
Ehitajate tee 5, 19086 Tallinn, Estonia
Phone: (372) 620 3270,
Fax: (372) 620 3250,
E-mail: tarmovelsker@hotmail.com

11. ADDITIONAL DATA ABOUT AUTHORS

PhD. Jüri Majak
TUT, Department of Machinery
Ehitajate tee 5, 19086 Tallinn, Estonia
Phone: (372) 620 3254,
Fax: (372) 620 3250,
E-mail: jmajak@staff.ttu.ee

PhD, Prof. Martin Eerme
TUT, Department of Machinery
Ehitajate tee 5, 19086 Tallinn, Estonia
Phone: (372) 620 3270,
Fax: (372) 620 3250,
E-mail: eerme@staff.ttu.ee

PhD. Meelis Pohlak
TUT, Department of Machinery
Ehitajate tee 5, 19086 Tallinn, Estonia
Phone: (372) 620 3254,
Fax: (372) 620 3250,
E-mail: meelisp@staff.ttu.ee