680. Development of plough using finite element method

G. Janušas[1], A. Palevičius[2], R. Palevičius[3], D. Gintauskas[4]
[1, 2, 4] International Studies Centre, Kaunas University of Technology
A. Mickevičiaus 37, LT-44244 Kaunas, Lithuania
[3] Department of Multimedia Engineering, Kaunas University of Technology
Studentų str. 50-411, LT-51368 Kaunas, Lithuania
E-mail: [1] *giedrius.janusas@ktu.lt*, [2] *arvydas.palevicius@ktu.lt*,
[3] *ramutis.palevicius@ktu.lt*, [4] *domantas.gintauskas@gmail.com*

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Abstract. Agriculture and the use of ploughing tools have been very important for the civilization for thousands of years. However, many changes took place in the field of ploughing during the last 30 years. About 54% of Lithuania is covered by agricultural land, therefore development and production of agricultural equipment is very important. The research object of this paper is the block of plough manufactured in joint stock company "Gamega ir Ko" in Lithuania. Main failures of these products are of mechanical nature: fractures, cracks, sags and other deformations of structural parts. The most important factors for the users of ploughs are strength and endurance properties, reliability, easy maintenance and repair. Purpose of this work was to develop a solid model of the plough using finite element method with subsequent analysis of the ploughing process including stress calculations at different workloads, thereby allowing prediction of crack generation when the plough hits the hidden stone or other obstacle in the soil.

Keywords: block of the plough, stresses, deformation, strength, safety factor, ANSYS Workbench.

Introduction

After the regaining independence, part of the industrial organizations, that relied on Eastern raw materials and markets bankrupted. New ventures were emerging, that were subcontracting for multinational companies for individual elements production. In this case the use was made of good geographical location of the country, ability to accomplish products qualitatively and in time, according to the requirements of "just – in – time" manufacturing. Nevertheless, together with the European Union (EU) expanding to the East, it is the time again to start product development, with some of its components made at the cheaper labor-force countries.

A product development process is the entire set of activities required to bring new concept to a state of market readiness [1, 2]. This set includes everything from the initial inspiring new product vision, to business case analysis activities, marketing efforts, technical engineering design activities, development of manufacturing plans, and the validation of the product design to conform to these plans. Often it even includes development of the distribution channels for strategically marketing and introducing the new product. Development of agricultural equipment is important for Lithuania due to its agricultural and historical traditions.

Agriculture and the plough were very important for the civilization for thousands of years [3-5]. But many changes arise in plough and ploughing during the last 30 years. For example, the reversible plough now dominates and more powerful tractors are used in ploughing process. Lithuania is agricultural land too. It is situated in the middle of Europe, with an area of 65,305 km^2, 58,794 km^2 of which are covered by soils. Agricultural land in Lithuania covers 3,496,761.27 ha.

Since the process of tillage is so important, many interesting and important scientific problems could be found.

The object of this paper is the block of plough manufactured in joint stock company "Gamega ir Ko" in Lithuania. It is used in combination to form 2, 3 or 4 furrows ploughs depending on frame to which is attached for cultivation procedure of the soil. Agricultural implements such as preplant aggregates for soil cultivation, coulter harrows, stubble scrapers, hiller ridgers, garden haymakers and similar are mostly used as trailing components for tractors or other mechanisms, they don't have any electromechanical components, just few or even no moving parts. Also, the accuracy requirements for these mechanisms are not high. In addition, it is safe to say that main breakdowns of these products are mechanical ones such as fractures, cracks, sags, and other deformations of structural parts. That is why the most important criteria for customers (farmers or companies of agro – industry) are strength and endurance properties, reliability, easy maintenance and repair as well as cost-effectiveness. Because of these reasons, in order to ensure competitiveness of furrow plough, the first and the most important step are to produce good block of the plough. Before mass-production of the plough many problems should be solved. Therefore analytical and empirical models are used to analyze soil–plough interaction, mechanical properties of plough surfaces [6-8], plough influence on soil erosion [9-11], surface design modifications [12, 13], measurement of the specific draught [14, 15], etc. The latest advances in computer and software could significantly assist in optimizing the s designs and operational conditions [16-18] aiming at minimum draught requirement and best soil manipulation performance [19, 20].

Purpose of the paper is to develop finite element method of a plough. Analysis of ploughing process, stress calculations of plough block at different workloads is subsequently conducted with results and conclusions presented at the end of the paper.

Ploughing process

The plough is a tool used in farming for initial cultivation of soil in preparation for sowing seed or planting. It has been a basic instrument for most of recorded history, and represents one of the major advances in agriculture. The primary purpose of ploughing is to turn over the upper layer of the soil, bringing fresh nutrients to the surface, while burying weeds and the remains of previous crops, allowing them to break down. It also aerates the soil, and allows it to hold moisture better. In modern use, a ploughed field is typically left to dry out, and is then harrowed before planting.

In the past two decades plough usage has reduced in some areas (where soil damage and erosion are problems), in favor of shallower ploughing and other less invasive tillage techniques.

There are a lot of differences in the cultivation of the soil: for different plants, various surface, soil structure, climatic zone, traditions, technique and equipment. First of all there can be ploughs of basic and special purposes. Ploughs of basic purposes are designed for ploughing topsoil, while the special ones are used in more difficult conditions. Above classification can involve ploughs designed for stony, (rocky) non-stony soils, also fixed and variable ploughing width ploughs. According to ploughing method the devices can be single-sided and both-sided (steady ploughing). According to the connection method the ploughs are classified into suspended, partly – suspended and trailing.

Despite the fact that soil cultivation by ploughing is probably one of the oldest methods used by human in agriculture from the beginning of agriculture, which is not changed significantly during a thousands of years and which used the same principles and just the more modern materials, design and manufacturing techniques are used nowadays. It is necessary to understand that ploughing is not simple process and it has range of requirements in order to prepare soil qualitatively and achieve good farming results. It is obvious that all strict requirements for ploughing process can be met just with the help of up–to–date agricultural implements, appropriate material, design, and manufacturing used and experienced worker (tractor – driver) also. It is not enough just to have experience or very good ploughing equipment. All these components must work together and with no mistakes or breakdowns in order to achieve the required results.

In this paper block of the plough was chosen to analyze because it is the main and the first most important component in block-frame-tractor-human system of ploughing because well designed block is the initial part, which is directly in contact with the soil while ploughing. It is not possible to meet the requirements of agricultural engineering in any way if there is some mistake in manufacturing process or, especially, in design of the block made.

Stress calculation

Block of the plough is in direct contact with the soil during the process of tillage, this unit is more sophisticated, made of several different parts and the repair of it is more difficult in case of breakdown. Also, block of the plough is more applicable structural component because the same block with no or very little modifications can be used in various types of frames and for different number of furrows (1, 2, 3, 4, 6 or even more furrows ploughs can be made, as well as reversible, inclinable, swinging or with across positioned blocks) depending on the available power of the tractor, structure of the soil, size of the fields and many other factors.

As it was mentioned before, the block of the plough is the main working component of the plough that determines the quality of the tillage according to its design and geometrical forms of the parts. It is a complex element made of several parts. According to the type and purpose of the plough the block can have some different parts but almost in all cases main parts are the same and perform similar functions. In this paper block of one of the most popular two-furrow plough was chosen for analysis. It is illustrated in Fig. 1.

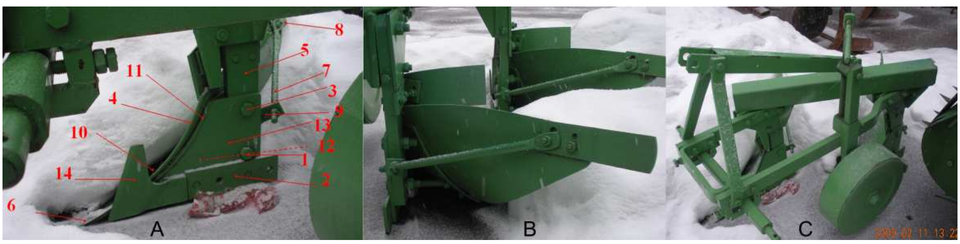

Fig. 1. Blocks of the plough front (a), back (b) and top (c) views: 1-bolt; 2-runner; 3-bolt; 4-shell board; 5-leg; 6-chisel; 7-crossbar I; 8-nib; 9-support; 10-ploughshare; 11-supporting plate; 12-crossbar II; 13-side plate; 14-coulter

For the manufacturing of this block of the plough three different kinds of steel are used: constructional steel 3 for support, supporting plate, crossbar II, and side plate; steel 45 for bolt, shell board, leg, crossbar I, and nib, and steel 65G for runner, chisel, and ploughshare. Mechanical properties of the steels used for this modeling are presented in Table 1, where: σ_{yt} - tensile yield strength; σ_{ut} - tensile ultimate strength; σ_{yc} - compressive yield strength; E- Young's modulus; v - Poisson's ratio; ρ – density.

Table 1. Mechanical properties of steels

Steel No.	σ_{yt} ,MPa	σ_{ut} ,MPa	σ_{yc} ,Mpa	E, GPa	v	ρ, kg/m^3
3	235	400	235	200	0,3	7850
45	353	640	353			
65G	785	981	785			

After defining materials used for manufacturing block of the plough it is necessary to determine workloads which plough has to withstand during tillage. Because the task of modeling is to analyze design of the block, in order to get the basic view about block behavior at different workloads it is enough to apply simplified evaluation of forces acting on it. In order to determine the most common forces acting upon modeled block of the plough we used data from [21] in which draft resistance R_x was determined by the following formula:

$$R_x = \sum R_{ix} = R_{Px} + R_{Gx} + R_{Jx} + R_{Ax} + R_{Ox} \quad (1)$$

where: R_{Px} - share cutting resistance, R_{Gx} - resistance caused by weight of the strip lifted, R_{Jx} - inertia forces, R_{Ax} - soil adhesion, R_{Qx} - weight of the plough block itself (including a part of the weight of the plough) [21].

Workload forces for the plough block with generatrix of 40° varies between 3500 N and 6000 N, when tillage speed is from 2 m/s to 5 m/s [21]. If the structure of the soil is uniform in all volume being cultivated all these forces are distributed upon all working surface (shell board, ploughshare and chisel): 40 % of the workload is applied to upper surface of shell board, 35% for ploughshare and 25% for chisel surface. But when the plough block meets obstacle force distributed over all surface acts at the one point or small surface area where obstacle touches surface becoming no more distributed but concentrated and having the same magnitude. Because force magnitude is the same and the area becomes much smaller such circumstance creates much higher stresses, which can lead to irreversible deformation and damage to the implement. The task of modeling is to check whether or not maximal stresses at the highest workloads exceeds yield or ultimate strength limits therefore the paper presents the results only for the force of 6000 N.

In order to evaluate and check design solutions, selection of materials, stiffness and stresses in the block two different software solutions were used. Drawings of the structural parts and assembly of them was made with the help of AutoCAD Mechanical 2008, while all the numerical calculations were performed with ANSYS Workbench.

Results

During normal tillage process the highest stresses (110 MPa) are formed in the place where shell board (part No 4) is fixed to the leg and in the leg below fixing place (Fig. 1), and they are 3 times lower than material yield strength (353 MPa) of the leg. Maximal deformation is undergone by the tip of the nib and it is equal to 1.64 mm. In order to find the most dangerous places in the plough where stress concentration increases and resulting deformations 8 different situations were modeled by applying all force equal to particular draft resistance to one point, small area or one edge of the working parts of the plough.

When the force is distributed over all surface of chisel or over all lower edge of the chisel (Fig. 2a) or side edge of chisel maximal stresses are located in the same places (Fig. 2b) as during normal tillage process, just magnitude increases up to 163.66 MPa for the first case, 210.61 MPa for the second and 174.64 MPa for the third. So force concentration on the different areas of the chisel changes maximal stress in the plough block by 46.95 MPa, but it is still 32% less than material yield strength.

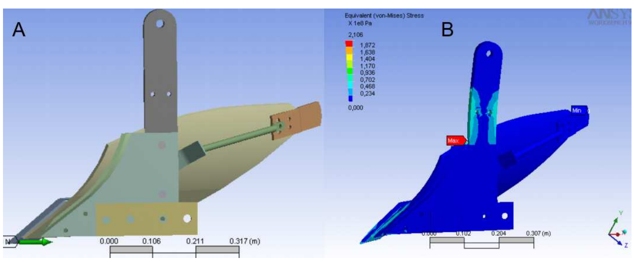

Fig. 2. Force of 6000 N is concentrated on lower edge of chisel: a) force concentration place; b) stresses

Other working part which is in direct contact with the soil during tillage is shell board. When plough hits an obstacle, force can concentrate on the side edge (Fig. 3a) or over upper surface of it (lower working surface is not investigated because most of it are covered by ploughshare and chisel).

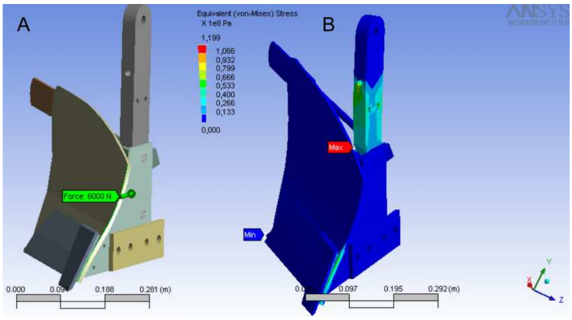

Fig. 3. Force of 6000 N is concentrated on the side edge of the shell board: a) force concentration place; b) stresses

Depending on the place of force concentration the highest and lowest stress values of 331.57 MPa for the first case (Fig. 3b) and 119.89 MPa for the second case can be reached in the place where the shell board is fixed to the leg, which is similar to the workloads applied onto chisel. But maximal stress is much higher (331.57 MPa). It is just 6% less than yield strength (353 MPa) of the leg material.

The last considered condition of force concentration is only at one point at the vertex of the chisel, which can lead to very high stresses. Despite the fact that area of the chisel vertex is extremely small compared with the total working surface of the plough block, the possibility for obstacle (e.g. hidden stone) to hit that vertex is fairly high because of its position which is located all the block ahead. Model of this situation is represented in Fig. 4.

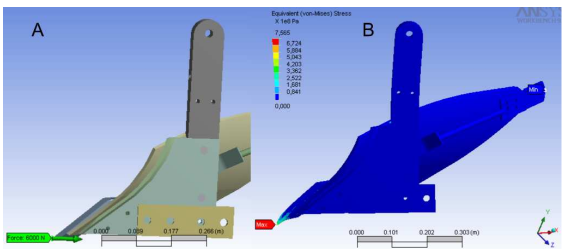

Fig. 4. Force of 6000 N is concentrated on vertex of chisel: a) deformations; b) stresses

As it were predicted, the obtained numerical results reveal that stresses of 756.49 MPa are more than twice higher in this case when compared with the highest stress value generated by the force over upper working surface of shell board and nearly reaches the yield strength limit of 785,0 MPa.

All the results could be concluded using safety factor. Safety factor of this plough is 1.04 against yield strength and 1.3 against ultimate strength. These results demonstrate that it is not safe to use plough block for speeds higher than 5 m/s (18 km/h).

Conclusions

Finite element model of the plough block manufactured in company "Gamega ir Ko" was developed in order to determine critical places and to calculate safety factor. Maximal stresses were observed at the point of fixing of shells board to the leg (331.59 MPa) and in the chisel vertex (756.49 MPa). Safety factor of this plough is 1.04 against yield strength and 1.3 against the ultimate strength. So it is not recommended to use this plough for speed higher than 18 km/h.

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