# The technical and theoretical support at construction of the 3-axis CNC milling machine with focus on the balancing of the vertical axis „Z“

Ing., Petr, Vašata

Leader of the thesis: Ing., Jan, Machyl, Ph.D.

***Abstrakt***

*Tento článek se zabývá návrhem mechanismu vyvažování vertikálního pohybu vřeteníku u 3osé CNC frézky. Je použit známý princip, upravený pro konkrétní stroj. Frézka je navržena podle potřeb zadavatelské firmy. Při řešení je kladen důraz na jednoduchost, ekonomickou nenáročnost a zároveň účinnost vyvažovacího mechanismu. Zadavatel využije tento mechanismus při výrobě CNC frézky. Stroj bude sloužit pro vlastní účely firmy.*

***Klíčová slova, key words***

*vertikální, vyvažování, vřeteník, gravitační, excentrická, kladka, pružina, mechanismus, frézka, vertical, balancer, spindle head, gravitate, eccentric, pulley, spring, mechanism, milling machine*

## 1. Introductions

The paper treat of a kinematical and strength design of the balancing mechanism of a spindle head’s vertical motion (axis „Z“). The spindle head is a part of the 3-axis CNC milling machine. The milling machine is shortly described in the paper. This milling machine is in the stage of 3D model and it is prepared for realization.

Proposed balancing mechanism is used on the smaller CNC milling machine. It was realized last year. Spatial arrangement is different but principle is identical. It will be shown at the end of the presentation. This smaller machine certainly serves for submitting company.

The basic principle of the balancing mechanism is an equality of the moments on a eccentric pulley (F*ig.1*). Left side of the formula contains a constant force of a spindle head and a variable radius of a eccentric pulley in Archimedes´ spiral shape. There is a variable force of a spring and constant radius of a „spring pulley“ on the right side of the formula. Eccentric and spring pulleys are firmly connected.

The result of described solution is design of the balancing mechanism for concrete CNC milling machine. This mechanism was solved in a thesis. This thesis contains the retrieval about used ways of balancing. It will be shortly shown in this paper.

$$G \cdot R(x) = Fp(x) \cdot r$$

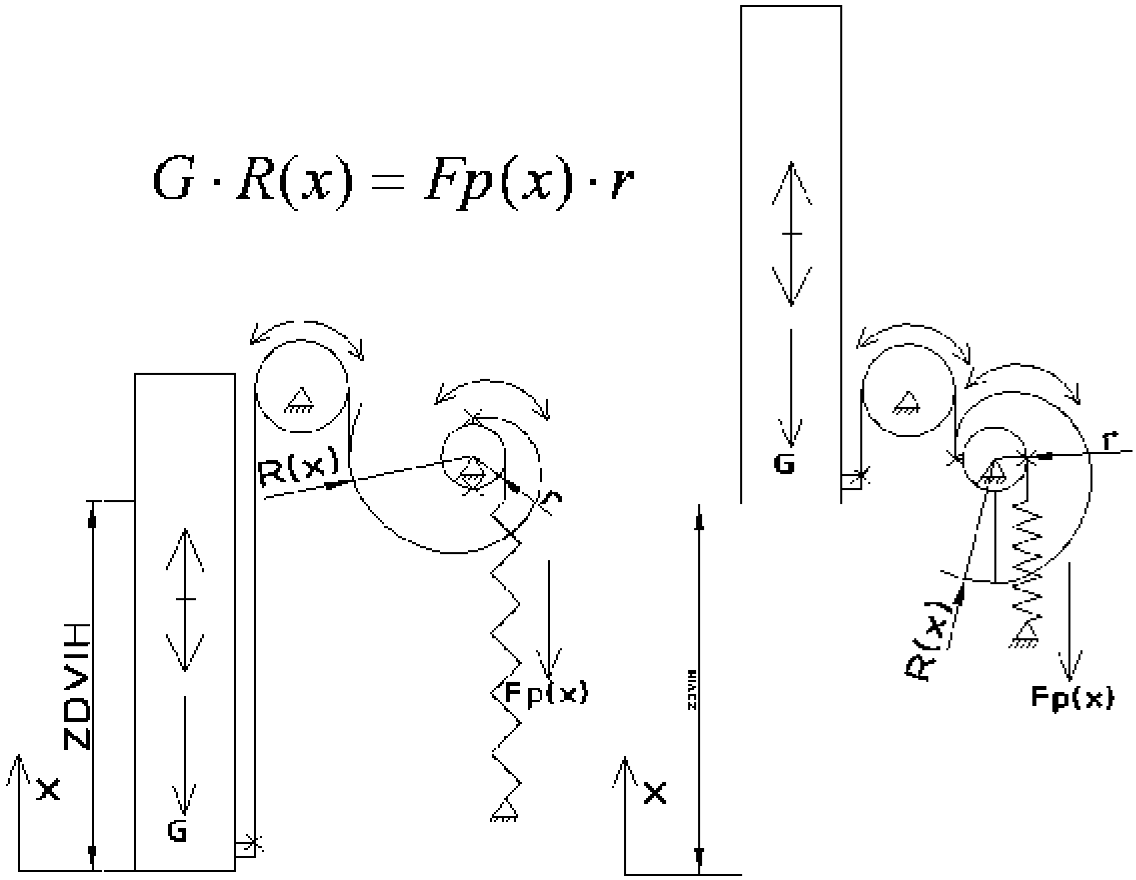


***Fig. 1*** *Basic principle of the balancing mechanism with equation of the moments*

## 2. Description of the CNC machine

The balancing mechanism is a part of the 3-axis CNC milling machine. Conception of a kinematical motion is (0-X,Y,Z). There will be made just only one piece. Primarily it will be used for machining aluminium moulds on vacuum forming of plastic palettes. *Fig. 2* shows an example of the mould and palette. Construction is adapted by these facts. The supporting structures are welded from plates and closed profiles, filled by polymer concrete. There is an exchanger of tools on the machine. Axes are driven by stepper electro engines and ball screws. For measuring are used IRC sensors (indirect measuring). Control system is its own. On the machine there are used classic roller linear bearings. Head stock has an electro spindle with automatic fixing of the tools. Global conception of the machine and storage of the balancing mechanism is on ***Fig. 3***.

*Fig. 2. Left: plastic palette made by vacuum forming, right: mould from aluminium alloy.*

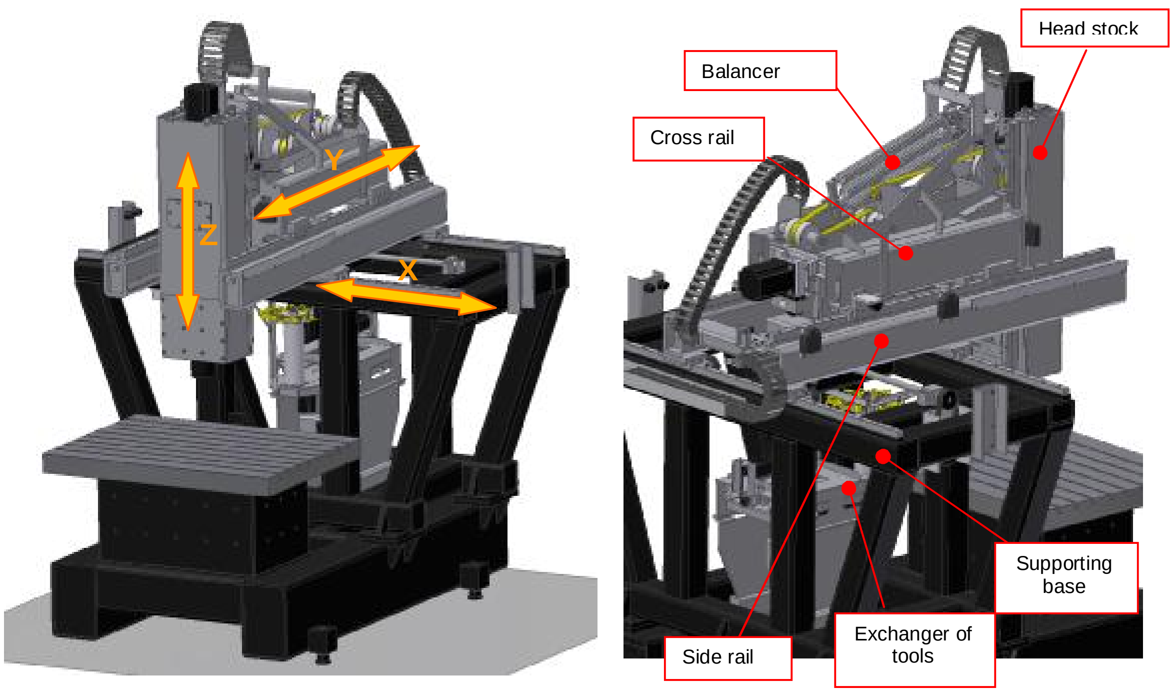


*Fig. 3. Model of milling machine.*

## 3. Short view of balancing systems practically used on machine tools

There are three basic systems used on machines:

- § mechanical balancing
  - § opposite weight (*Fig.4*)
  - § mechanical balancing consumed energy (for example electrical) – mainly used on machines for assembling of heavy parts
  - § spring mechanism – solution of this thesis, another example on *Fig.7*

- hydraulic balancing
    - hydraulic pistons with gas accumulator (*Fig. 5*)
    - hydraulic pistons se loading accumulator
- pneumatic balancing
    - medium is air or $CO_2$ (*Fig. 8*)
    - medium is nitrogen ($N_2$ pistons, *Fig.6*)

Pneumatic balancing mechanisms are the most used today. It has good dynamic and shape properties. On smaller machines are no any balancing systems. It is possible to balance head stock or table (less used).

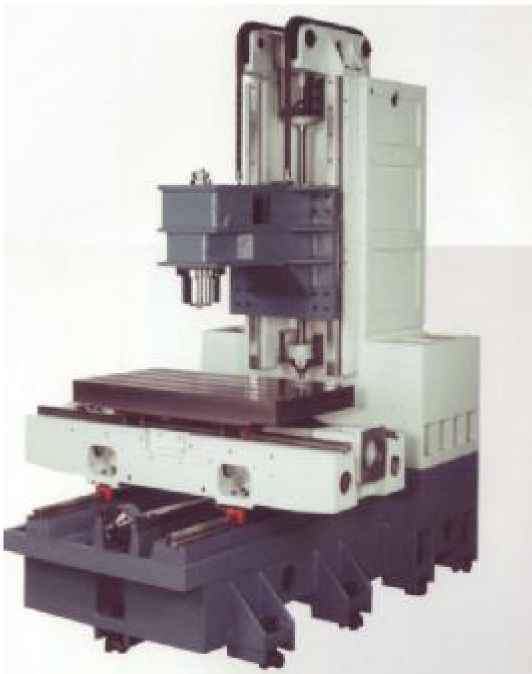

***Fig. 4.*** *Using of opposite weight on milling machine, Sunmill*

***Fig. 5.*** *Hydraulic balancing, TOS Varnsdorf. [3]*


***Fig. 6.*** *Pneumatic balancing $N_2$, Pascal y.[1]*

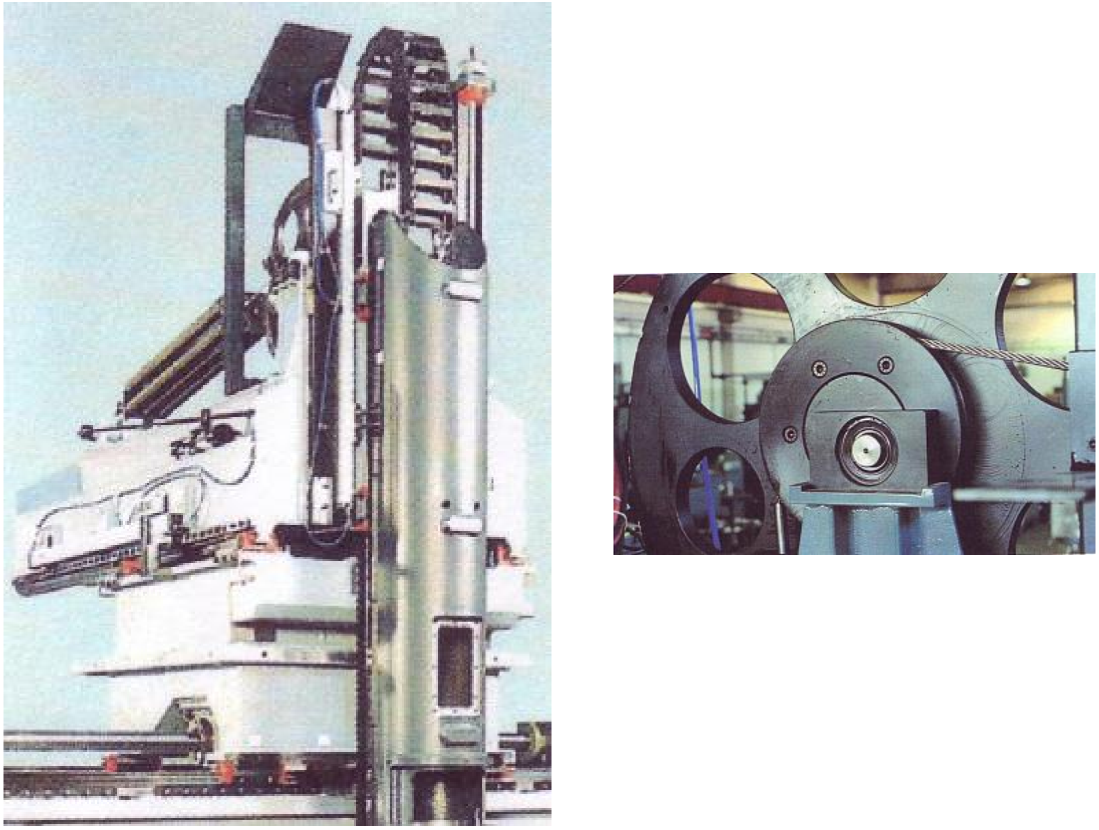

***Fig.7.*** *Spring balancing on milling machine D156, Fidia [4]*

***Fig. 8.*** *Pneumatic balancing $CO_2$, CNC Technology.*

## 4. Developmental variants of storage the mechanism in the machine

Conception of the balancing mechanism was changed several times during development of the machine. On *Fig. 9, 10, 11* there are shown three basic variants with description of the positive and negative properties.

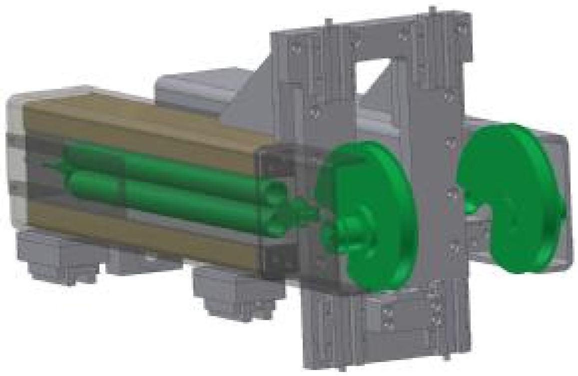

*Fig. 9. The First variant of storage of the balancing mechanism*

The first variant:

- using of cavity in closed profile
- without guiding pulley
- limited access during service
- complicated covering

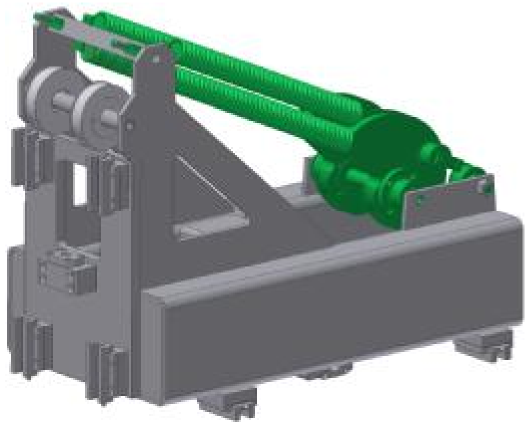

*Fig. 10 the Second variant*

The second variant:

- compact solution of storage
- easier covering
- lover weight then variant 1
- inserted pulleys
- lower efficiency

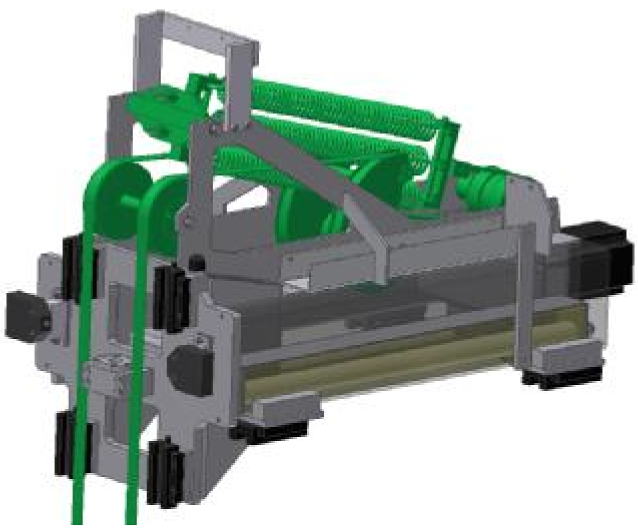

*Fig. 11 the third - Used variant*

The third variant – selected version

- compact version
- easy covering
- higher stiffness then var.2
- inserted pulleys
- lower efficiency
- partial combination of kinematical conception of the first version and storage into frame of the second version

### 4.1 Description of the selected variant

Balancing mechanism is stored in a cross rail part. It moves in Y axis (*Fig.3*) directly and in X- axis via frame member. This solution satisfies following requirements:

- possibility to make parts by own devices of small company

- reliability (almost without servicing)
- effectivity
- mechanism without using medium like air or oil
- low costs

Spring and pulleys are connected by textile band. Force of spring is possible to set by setting screw. Model with description is on Fig. 12.

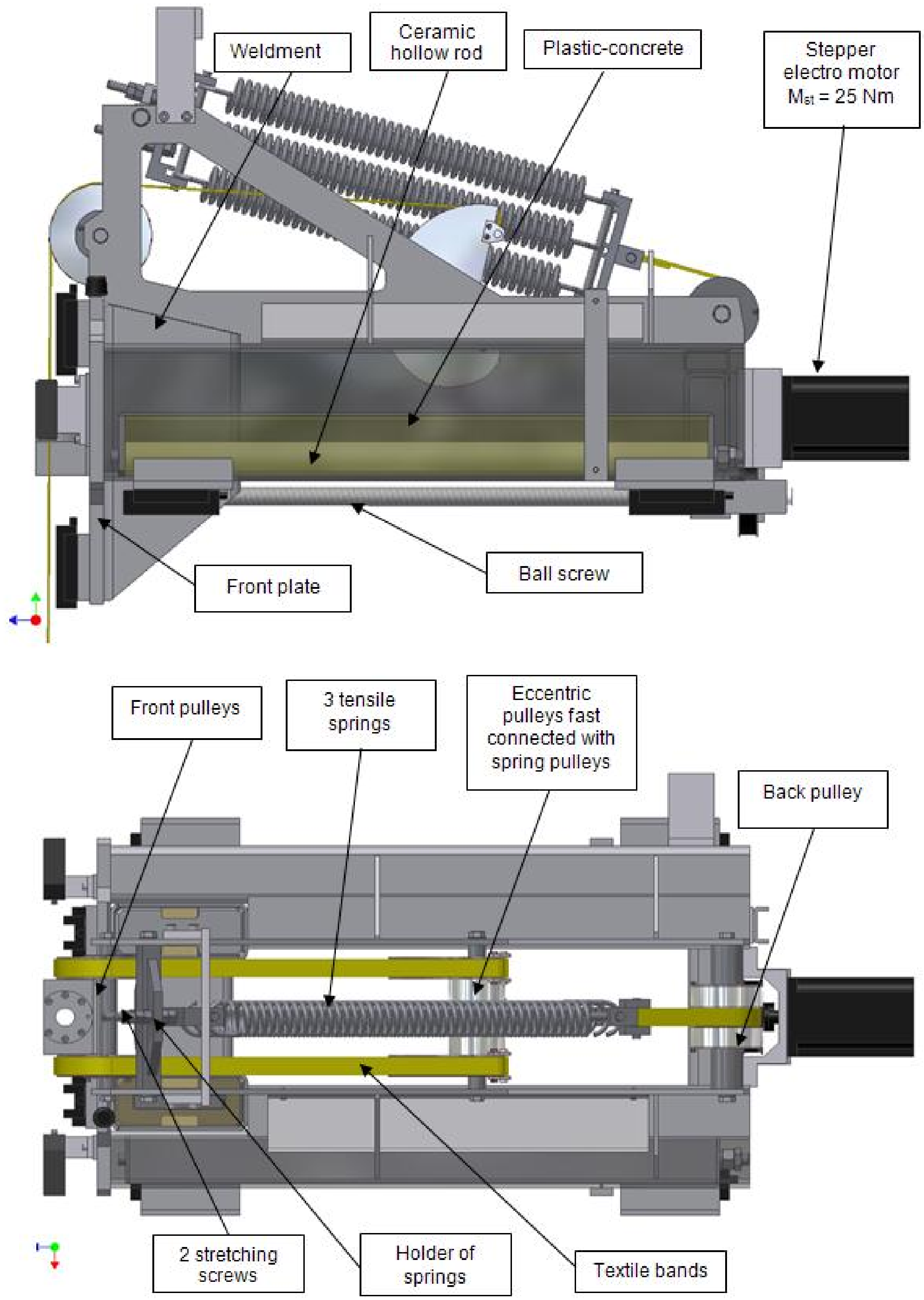


***Fig. 12*** *Model of cross rail-top and side view*

## 5. Procedure of calculation of components

In calculation part of the thesis there is firstly selected spring according to input parameters like balanced weight, stroke of the head stock. There are selected three springs in parallel ordination. Basic parameters of the spring are on *Fig.13*. Secondly is designed profile of the eccentric pulley according to equation on *Fig.2*. The model´s detail of the eccentric pulley is on *Fig.14*.

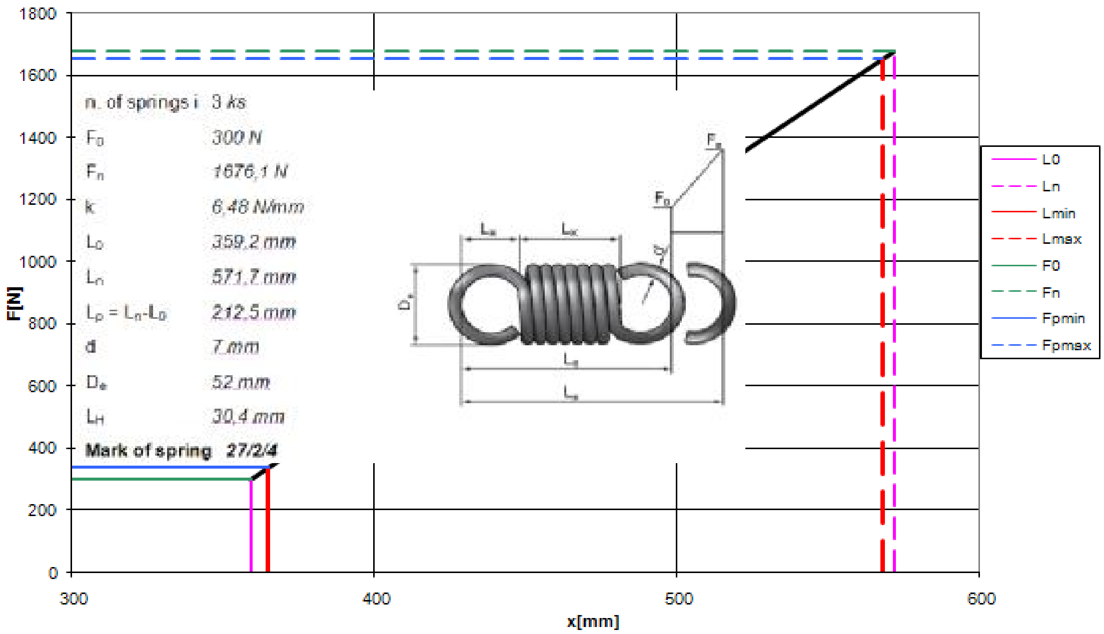


***Fig. 13*** *Parameters of spring and working area of the spring [2]*

It was selected the bearings, basic parts were statically and dynamically checked after definition of the occuring forces. There are used self-aligning ball bearings. It allows to neutralize eventual manufacturing inaccuracys. In case of the shafts and the holder of the springs was investigated bending curve (*Fig.15*). It was used MKP method on the holder of the springs. The eccentric and the back shafts and the holder is stressed by cyclic tensionis therefore it is checked on fatigue safety by using Haigh´s graph. Example of the Haigh´s graph for the shaft of the eccentric eccentric is on *Fig.16*.

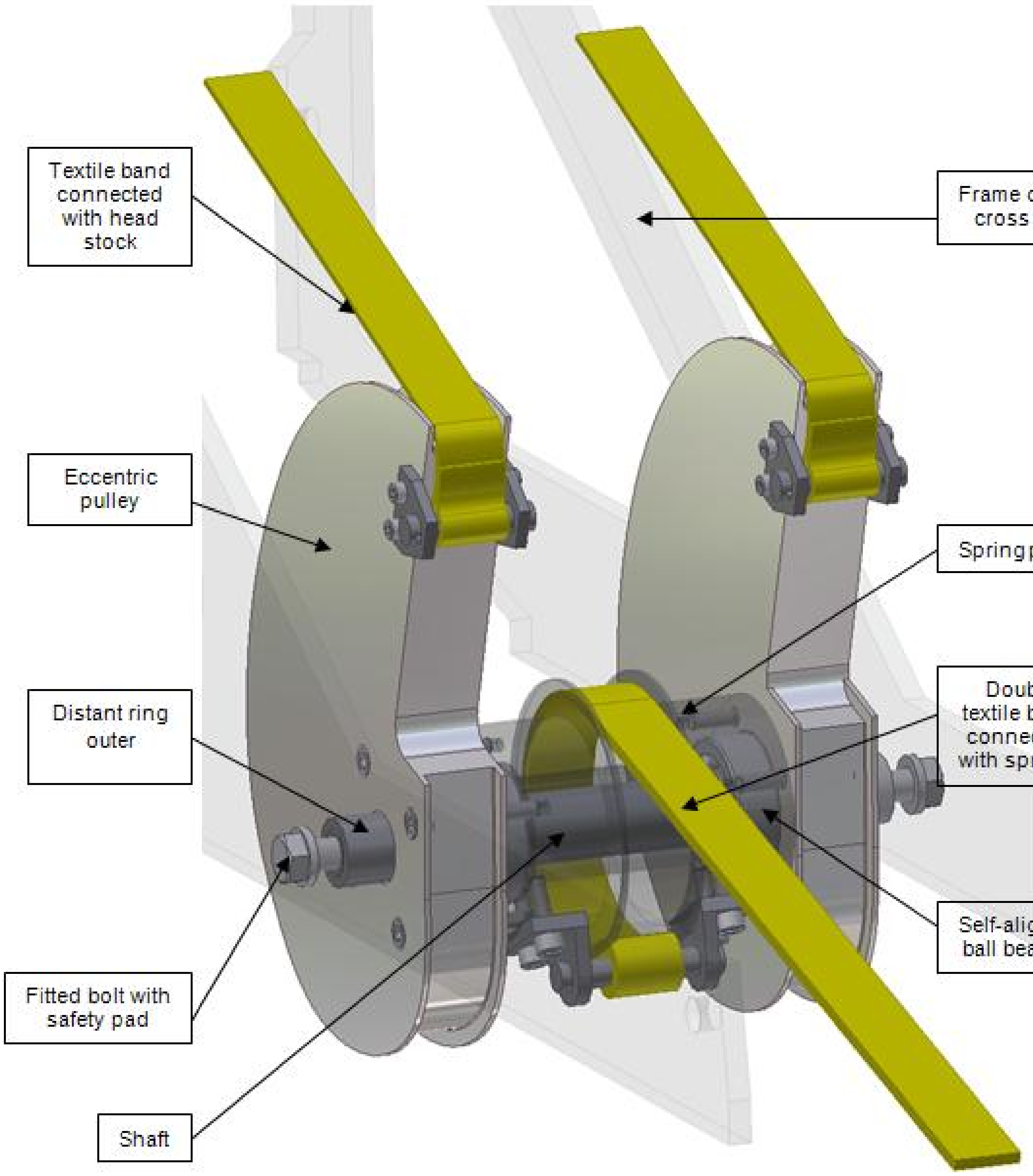


***Fig. 14*** *Detailed model of the eccentric pulley*

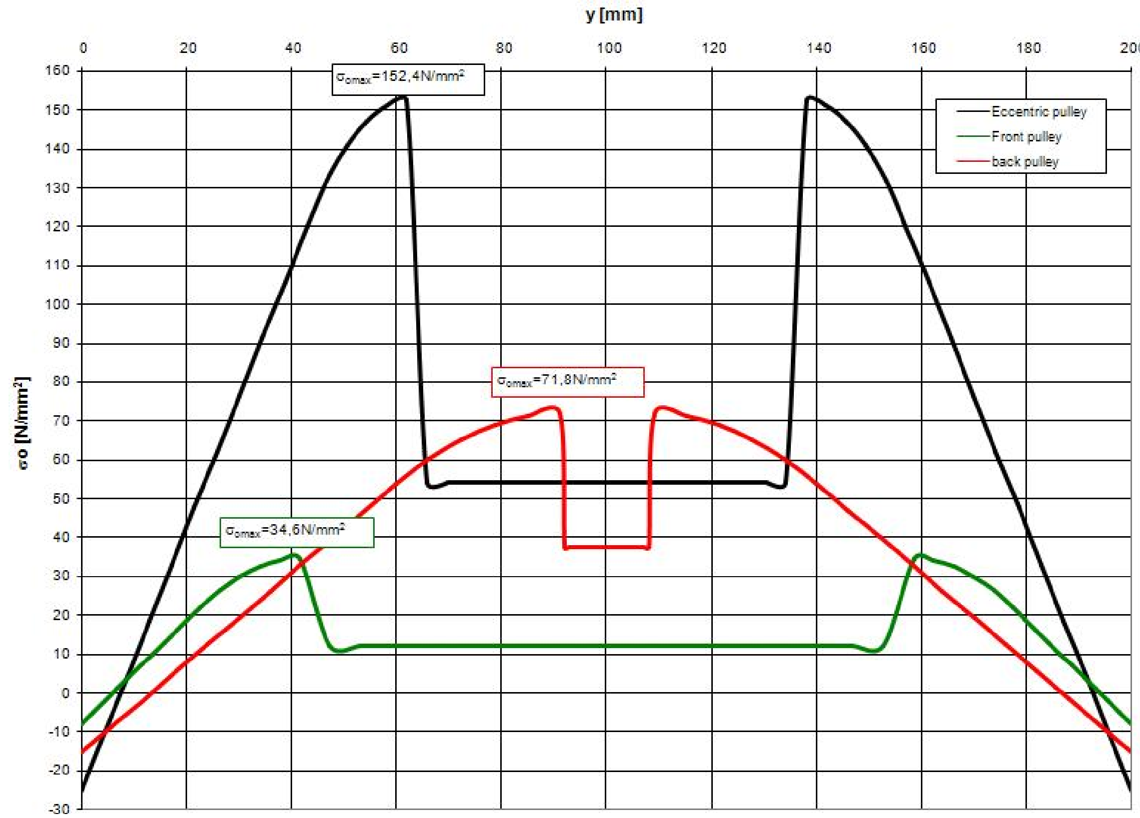


***Fig. 15** Bending curves of the pulleys*

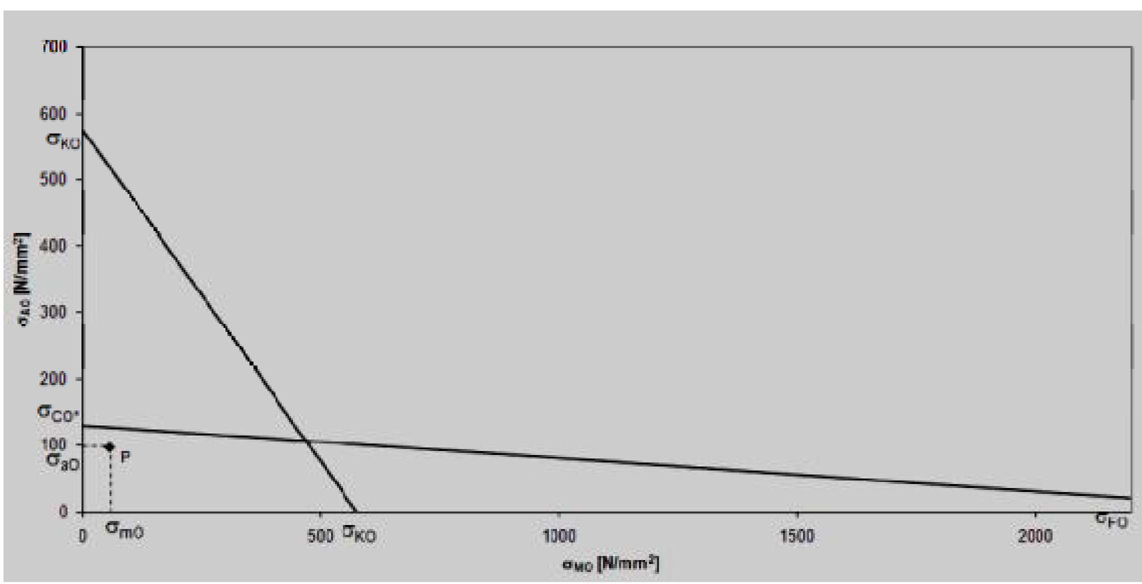


***Fig. 16** Deflection curves of the pulleys (Haigh´s graph)*

## 6. Conclusions

There were made kinematical and strength calculations of all important parts of the balancing mechanism. All calculations satisfy static and fatigue conditions. This mechanism is suitable for machine tools with slower and not too long motions of balanced parts. In the supplement of the thesis there is an easy program for setting of the input parameters. By the help of this program it is possible to design quickly eccentric pulley and springs. In introduction was mentioned that this mechanism has been already used on smaller CNC milling machine. In this case there is used only one eccentric pulley and one spring. Application is shown on *Fig. 18*.

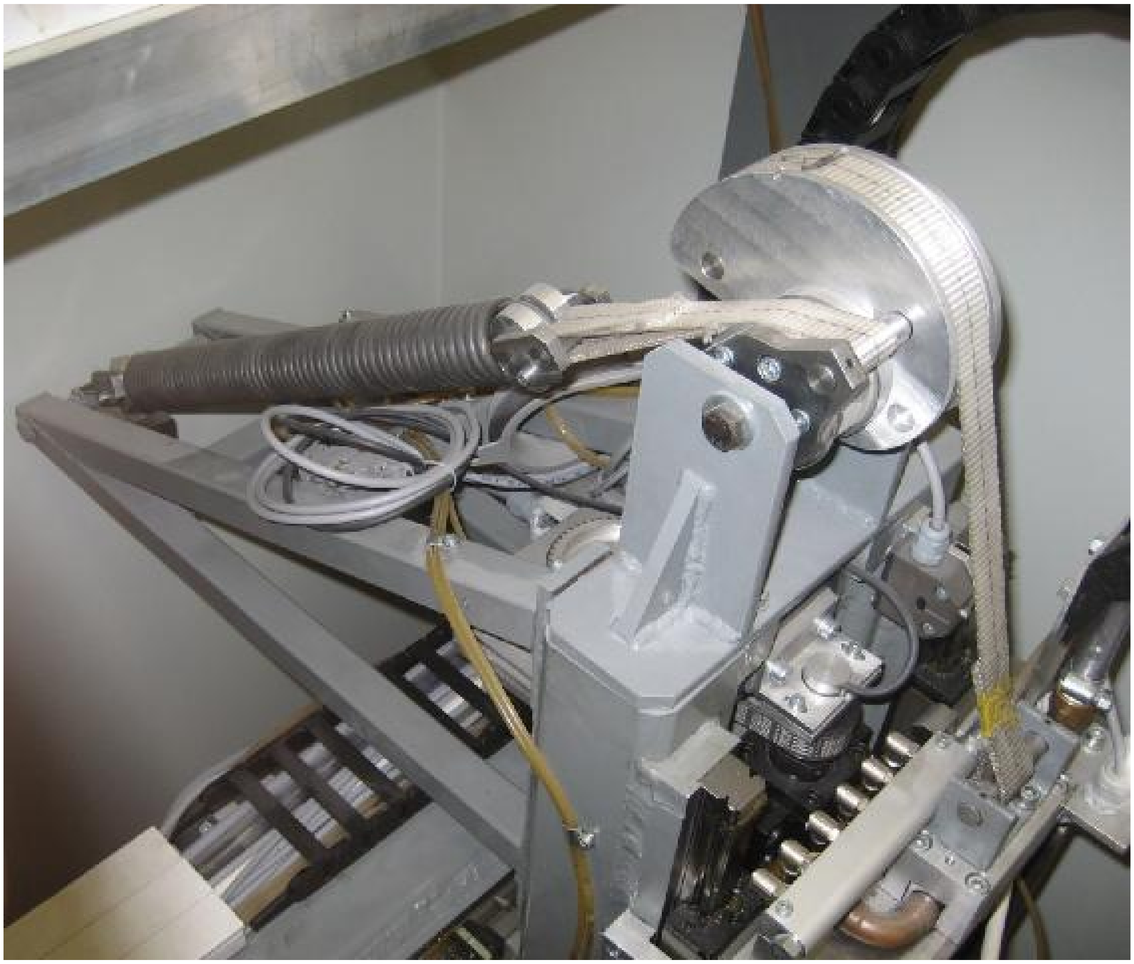

***Fig. 17*** *Application of the balancing mechanism on the CNC milling machine, upper position*

The designed balancing mechanism is applied on the concrete machine. This mechanism has to meets specified criteria. These criteria are: easy availability and manufacture of particular parts in environment of small company, low cost, reliability and maximal efficiency. The balancing mechanism meets these criteria. Main target of the mechanism is to reduce difference between vertical motions up and down of the head stock. Therefore is possible to use weaker electro motors and decrease electrical consumption.

***Nomenclature***

| | | |
|---|---|---|
| Q | weight of the head stock | [N] |
| R(x) | variable radius of the eccentric pulley | [mm] |
| r | radius of the “spring pulley” | [mm] |
| $F_p(x)$ | variable force of the spring | [N] |
| $F_0$ | preload of the spring | [N] |
| $F_n$ | maximal load of the spring | [N] |

| | | |
|---|---|---|
| $k$ | stiffness of the spring | [N/mm] |
| $L_0$ | length of the unloaded spring | [mm] |
| $L_n$ | length of the fully loaded spring | [mm] |
| $L_p$ | stroke of the spring | [mm] |
| $d$ | diameter of the spring wire | [mm] |
| $D_e$ | inner diameter of the spring | [mm] |
| $\sigma_{Omax}$ | maximal value of the bending tension $\sigma_O(y)$ | [N/mm$^2$] |
| $\sigma_O(y)$ | course of the bending tension during maximal load | [N/mm$^2$] |
| $\sigma_{mO}$ | middle tension of a bending cycle | [N/mm$^2$] |
| $\sigma_{aO}$ | amplitude of a bending tension | [N/mm$^2$] |
| $\sigma_{CO}^*$ | limit of a fatigue of a rod with tooth in bend | [N/mm$^2$] |
| $\sigma_{KO}$ | limit of a slip in bend | [N/mm$^2$] |
| $\sigma_{FO}$ | fictive tension | [N/mm$^2$] |

***References***


[1] Pascal corporation. Itami, Hyogo, Japan. Pascal N2 Gas Balancer. 2007, 16 stran.

[2] Hennlich Industrietechnik spol. s.r.o. Litoměřice, ČR. Tažné pružiny, 7 stran.

[3] TOS Varnsdorf. Varnsdorf, ČR. Horizontální frézovací a vyvrtávací stroje. 2004, 10 stran.

[4] Fidia, San Mauro Torinese, Italy. D165. 1996, 6 stran.