BEP:
“Design of a guiding mechanism for the plasma needle”

Coaches:
ir. L.J.M. van den Bedem
Prof. dr. ir. M. Steinbuch

Gerbert van de Ven
Student nr.: 0557564
Abstract
In 2001 research from the Elementary Processes and Discharges in Gas Discharges group (EPG) at the Eindhoven University of Technology has led to the development of the plasma needle. This new type of plasma can be sustained at atmospheric pressure and operates at ambient temperature, making treatment of biological tissue possible. Research on the plasma needle is still in its early phase, the theory of plasma is mostly known, but virtually no practical data is available. The plasma needle was operated by hand and therefore test that were done are not representative and reproducible. Research has shown that the plasma itself can serve as a positioning sensor. The existing setup to control the position of the plasma needle has proven to give an insufficient result. Controllers tested on this setup were unstable and unable to control the position to the required accuracy. After reviewing this apparatus various suggestions will be done for improvements. A guiding system using aerostatic bearings is suggested as well as a system using leaf springs. Comparison of the two bearings show that in this stage of the research and with the proposed treatment area the latter option is the best suitable. This leaf spring arrangement is then worked out in more detail, giving an impression of the required actuator forces and various dimensions. Furthermore details are given on a voice coil actuator, the chosen actuator for the leaf spring design. After that a new design will be given for the plasma needle.
Table of contents

1. Introduction to the plasma needle research.................................................................4
   1.1 Plasma source........................................................................................................4
   1.2 Plasma needle.......................................................................................................5
   1.3 Using reflected power as a sensor........................................................................5
   1.4 Previously used control mechanism.................................................................6
   1.5 Scope of this report and future research.......................................................7
2. Design specifications ....................................................................................................8
   2.1 Treatment area....................................................................................................8
   2.3 Bandwidth of the various components.........................................................9
   2.4 Gas flow............................................................................................................9
   2.5 Electrical circuit...............................................................................................9
   2.6 Table of specifications...................................................................................10
3. Design options...........................................................................................................11
   3.1 Leaf spring guidance.........................................................................................11
   3.2 Aerostatic guidance.........................................................................................13
   3.3 Comparison.......................................................................................................14
   3.4 Leaf spring alignment in more detail............................................................14
   3.5 Selection of an actuator..................................................................................16
   3.6 Conclusion and recommendations for x-y guidance...................................17
4. Design of the plasma needle....................................................................................18
   4.1 The needle tip...................................................................................................18
   4.2 Suggestion for research concept.....................................................................20
5. Conclusion and recommendations on further research....................................21
Bibliography ................................................................................................................22
Appendices ...................................................................................................................23
   I. M-file Leaf springs............................................................................................24
   II. Formulas..........................................................................................................25
   III. Voice coil motors............................................................................................26
1. Introduction to the plasma needle research

Before continuing with this report, a summary of previous studies is given in order to give a clear view on the subject at hand. This means giving a brief introduction to the plasma source, the plasma needle, describing the use of reflected power as a sensor and discussing the previously used control mechanism. In the conclusion it will become clear what further research will look like and a goal for this report is stated. This chapter does not cover the full research done on the plasma needle, it merely summarizes known reports. For better understanding previous reports as mentioned in the bibliography, Appendix I, should be read.

1.1 Plasma source

First of all a definition for the term plasma is given. Plasma is identified as a state of matter with enough free charged particles for its dynamics to be dominated by electromagnetic forces [1]. Charged particles are a result of inelastic collisions between highly energetic electrons or photons with neutral molecules and atoms. Collisions of charged particles result in a gaseous or fluid-like mixture, containing molecules, free electrons, ions, atoms and radicals. Due to the fact that free electrons very rapidly cope with any disturbance in charge equilibrium, plasma is able to maintain a state of charge neutrality. Electrons are able to do this because of their very low weight. Often plasma is referred to as the fourth state of matter, besides the solid, liquid and gaseous state. When dealing with plasma there are roughly two major categories that can be identified, a high-temperature plasma and a low-temperature plasma. High temperature plasma (HTP) has a typical temperature of $10^7 \text{ K}$, caused by full ionization of the neutral particles. For low temperature plasma (LTP) a further subdivision is made based upon the equilibrium state of the plasma. In a non-equilibrium plasma, temperature levels of the electrons and ions differ a lot, where electrons reach a high temperature ($10^5 \text{ K}$) the ions remain at low temperature (ambient temperature is possible). In order to maintain a low temperature of ions, the plasma is operated at low pressure levels to avoid collisions between the atoms and the electrons. In an equilibrium plasma the kinetic energy of some of the neutrals is large enough to effect ionization [3]. Here the temperature of the electrons and ions is approximately the same ($10^4 \text{ K}$). In general these are referred to as thermal plasmas. For a clear overview Table 3.1 is added below, $T_e$ represents the electron temperature and $T_i$ the ion temperature.

<table>
<thead>
<tr>
<th>Low-temperature plasma (LTP)</th>
<th>High-temperature plasma (HTP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-equilibrium LTP</td>
<td>Equilibrium LTP</td>
</tr>
<tr>
<td>$T_e \leq 10^5 \text{ K}$</td>
<td>$T_e \approx T_i \leq 10^4 \text{ K}$</td>
</tr>
<tr>
<td>$T_e \gg T_i \approx 300 \text{ K}$</td>
<td>$T_e \approx T_i \geq 10^7 \text{ K}$</td>
</tr>
<tr>
<td>e.g. low-pressure discharge</td>
<td>e.g. arc plasma</td>
</tr>
<tr>
<td></td>
<td>e.g. fusion plasma</td>
</tr>
</tbody>
</table>
1.2 Plasma needle

In 2001 research from the Elementary Processes and Discharges in Gas Discharges group (EPG) at the Eindhoven University of Technology has led to the development of the plasma needle. It uses a new type of plasma source which can be described as a low temperature non-equilibrium capacitive coupled radio frequent plasma. It is produced by applying a radio frequent (RF) electrical field to a gas, in this case helium. The electrical field causes the charged particles to accelerate and collide with neutral particles, producing new charged particles and resulting in a partially ionized gas or a LTP. This network operates at 13.56 MHz, a worldwide accepted standard for applications that use RF signals. Furthermore the electrical field is created through voltage difference by a capacitive geometry, known as a capacitive coupled plasma. To give an impression of the plasma needle Figure 3.1 is added showing the needle schematically and a discharge.

Temperature of the plasma remains at ambient level, room temperature at this moment. When the generated plasma comes into contact with tissue it causes reactions which are currently being investigated. For more detail on the effect of plasma on living tissue a report written in Dutch is available [5].

1.3 Using reflected power as a sensor

Although the subject describing the interaction of plasma with living tissue is very interesting, it is not necessary to fully understand this when designing a guiding mechanism. A fact that is of importance is the relation between the distance of the plasma to the skin and the reactivity of the plasma. Quantifying the reactivity of the plasma with respect to the gap width, as done in Figure 3.2, gives an impression of the importance of positioning of the needle. Within the range of 2 mm (0 – 2) the number of radicals changes with...
approximately 10% for every 0.1 mm variation. As mentioned in the previous section, the applied dose of plasma determines the final result. For this reason it is desirable to control the position of the plasma needle with an accuracy of at least 0.1 mm. In order to control the distance a sensor is needed, previous research has shown that several existing methods were unsuitable [7]. Therefore research is done to use the discharge of the plasma itself as a position sensor. The electromagnetic waves of the radio frequent power sources reflect, much in the same way that sound waves partially reflect at a surface. This reflection, reflected power, can be used as an indication for the position of the needle. This hypothesis is tested in E. van der Laan’s study [4], in which is shown that a linear correlation exists between the dissipated power and the plasma dose. In order to use it as a sensor the following relation as shown in Equation 3.3.1 is important.

\[
P_{\text{dissipated}} = (P_{\text{forwarded}} - P_{\text{reflected}})_{\text{on}} - (P_{\text{forwarded}} - P_{\text{reflected}})_{\text{off}}
\]  

(3.3.1)

It shows the dissipated power is a function of a term related to the operating plasma needle and a term associated with the idle plasma needle. Because this last addition does not change in time and is a constant value, the first term in the equation can be used as an indication for the gap width. A change in distance to the skin cause a relative large variation on the reflected power in comparison to the forwarded power and therefore reflected power is used as a sensor.

1.4 Previously used control mechanism

A guidance system for the plasma needle has been manufactured after research done on this subject [8]. The designed mechanism is shown in Figure 3.3, as can be seen a single leaf spring is used to fix 3 degrees of freedom of the system. The remaining 2 are fixed by the voice coil motor, leaving the 6th, z-movement, as only free motion. This motion is driven by the motor to realize a displacement of the needle. This apparatus is tested and it is concluded that following behaviour at low frequencies is satisfactory, but lacks at higher frequencies. Distances in this experiment were measured by means of a laser distance sensor. Recommendations by the author show that improvements need to be done on the guidance, allowing the motor to make a straight z-movement and coping with the fact the single leaf spring has a rotational effect. This rotation cause extra friction in the system and needs to be avoided.

However this mechanism has been used in a study to control the plasma needle [9]. In this report it is stated that the system in this form will not be able to follow an input signal up to 5 Hz accurately enough. Friction in the motor due to the rotational effect is identified as the biggest source of inaccuracy. This causes a stick – slip behaviour which is difficult to control. Moreover the rotational effect causes the tip of the needle to displace more than 0.1 mm in other than z-direction.
1.5 Scope of this report and future research

Summarizing the previous reports it becomes clear that although a lot of research is already done, much more is needed to get a satisfactory result. First of all the guiding mechanism needs redesigning, this will eliminate the unwanted effects of friction and makes sure that controlling the needle is easier. Furthermore the electrical design needs verification and measurements on the matchbox are needed to check its operation.

In this report various options for the guiding mechanism in the z-direction will be presented. This report will first go over the design specifications in order to get a clear view on the desired outcome. Thereafter various design options will be mentioned and finally after comparison recommendations will be done how to improve on the current setup.
2. Design specifications

As mentioned in the previous section, it is of vital importance to control the position of the plasma needle with respect to the skin. In order to achieve good accuracy and robustness of the total system a guiding mechanism is necessary. Before designing such an instrument, a clear list of desired specifications is needed. Research on the plasma needle is still in its early phase and since there is little material from past research available, it is of the most importance to thoroughly investigate all the aspects. This chapter will consider the various design parameters separately in order to achieve a specifications table on which further design will be based.

2.1 Treatment area

Ultimately the goal is to be able to apply the plasma needle to a wide variety of surfaces, e.g. teeth, skin and veins. In order to specify design parameters a more quantifiable surface is needed. First of all the assumption of a flat surface is made, i.e. the only variation in height is the irregularity of the skin, which is plausible as long as the surface area is small. The surface area is assumed to measure 40 mm in both directions. Furthermore the variation in height is thought to be 2 mm at maximum. For better understanding Figure 2.1 is added, where the plasma needle tip is shown going over a piece of skin surface. The axes shown in the figure will be the directions used throughout this report.

2.1.1 Z-displacement

First of all the question arises whether or not the z-axis along which the probe moves is restricted to move in the x-y plane or that rotation about x and y is required. This becomes important when the plane on which the needle is operational is no longer perpendicular to the z-axis, e.g. the contour of a human arm. When this situation occurs the skin variation is no longer the only varying parameter that needs to be followed. For simplicity the z-actuation is considered separately form the x – y actuation. In this report it will be assumed that the only varying parameter in the z – direction is the irregularity of the skin, i.e. the needle follows a straight path when the skin is smooth. This assumption is justified as long as the z – variation is much less than the x – y variation, the guidance in x – y direction will be able to maintain a slow movement as the z – probe deals with the fast variance in the skin surface. Now the required travel of the needle has to be determined. Variation of the skin is assumed to be less than 2 mm at all times, so this value will be addressed to the fine stage z – movement. Research in the EPG group involves treating cells placed in an array of compartments and the needle must be able to reach inside such a compartment. More movement of the probe in this direction is clearly needed to be able to displace the needle sufficiently. Therefore a second stage will be added to this direction, allowing for a wider range of working area. This second, coarse stage will have a stroke of 20 mm.
2.1.2 Movement of the device in x – y direction

When z-direction movement is realised in such a way that it can cope with the irregularities in the skin, a system to move the z-probe along the surface is needed. For this mechanism less stringent demands are set on the bandwidth. Movement in x and y direction will be used to position the needle and to move it along a straight line or in the future along a small curvature. Irregularities will be dealt with by the z-probe. However it should be kept in mind that in a future situation where more speed is desired, the mechanism needs to be able to track the curvature sufficiently fast. For this report a flat surface is assumed and this surface is chosen to be 40 mm in both directions.

2.3 Bandwidth of the various components

In order to give an estimation of the required bandwidth of the various components it is necessary to know the treatment time and the area of effectiveness of the plasma. Here problems arise, because there is no available data to assure a certain treatment time. This is the object of research for which this guidance is meant. This parameter is mentioned here to make sure that it is not overseen; the guiding mechanism must be able to follow a certain unknown frequency.

2.4 Gas flow

To maintain the plasma a sufficient amount of helium must flow past the tip of the radio frequent powered needle. This inert gas accomplishes an environment at the tip where air is almost absent, this way the plasma can be generated. Van der Laan study’s show a minimum amount of 0.5 liter per minute is needed [4]. However tests have been done to generate plasma trough an injection needle. Here much less helium is required (<0.1 liter per minute), most likely to the fact it flows trough and not past the needle. This way air is blocked out more efficiently. To obtain a design parameter and to be able to vary designs, a speed of the plasma past the needle tip is chosen. This way the needle diameter can be varied. Minimum speed of the helium is thought to be 1 meter per second, based on measurements on the existing needle and the experimental setup with the injection needle.

2.5 Electrical circuit

Requirements are set on the various electrical components. Plasma is generated at the point where helium comes into contact with the powered metal wire. Insulation has to be added at points where plasma is not desirable, but where contact between the metal and the helium is made. This insulation has another goal, to keep the wire from turning into an antenna. Applying a radio frequent signal to a wire will otherwise cause a transmission.
2.6 Table of specifications

After discussing the various design parameters an inventory is made (Table 2.1), which will be used for further design of the guiding mechanism.

Table 2.1: Design specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement z-direction fine stage</td>
<td>2</td>
<td>mm</td>
</tr>
<tr>
<td>Movement z-direction coarse stage</td>
<td>20</td>
<td>mm</td>
</tr>
<tr>
<td>Movement x-direction</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>Movement y-direction</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>Gas flow</td>
<td>1</td>
<td>m/s</td>
</tr>
<tr>
<td>Accuracy displacement(^1)</td>
<td>&gt; 0,1</td>
<td>mm</td>
</tr>
</tbody>
</table>

\(^1\) Determined in previous study's, some details will follow in the next chapter.
3. Design options

Based upon the specifications given in the preceding chapter various designs will be considered. Although movement in x-, y- and z-direction is desired, focus will lie on translation in the z-direction. This is done because of the importance of the z-placement, which will determine the effect of the plasma on the skin.

Each design will have its own strong and weak points; this chapter is meant to give an impression about various options that were considered and what considerations were made to choose for a particular design. First of all a leaf spring guidance is considered, secondly a guidance based on air bearings is considered. In this chapter only the guidance is considered, in the next chapter the design of the needle itself will also be revised. Finally after discussing these options, a comparison is made in the end and more details are given on the chosen option.

3.1 Leaf spring guidance

In search of a frictionless guidance, the leaf spring is considered. The previously used control mechanism also relied on the use of leaf springs, but problems occurred due to rotation of the system and therefore displacement in unwanted directions. This is illustrated in Figure 3.1, showing a single leaf spring with excitation x and the distance delta x that it shortens. Therefore the use of a dual parallelogram is opted; correct use will result in no displacement other than in z-direction and therefore the motor can run frictionless. The next paragraphs will show the successive design steps, beginning with an analysis of the movement. Then after considering various options dimensioning of the leaf springs is done. Required driving forces are estimated based upon this dimensioning. Finally recommendations will be made for the x-y guidance.

3.1.1 Dual parallelogram construction

When using a dual parallelogram movement in other then z-direction can be suppressed by using a lever connecting the two separate parts of the construction. Figure 3.2 shows the dual parallelogram construction schematically and makes clear why such a lever is needed. In Figure 3.2a, one pair of leaf springs provides all the displacement and thereby nullifying the effect of a dual parallelogram construction creating a displacement delta y.
For correct operation a configuration as in Figure 3.2b is needed. Forcing such a configuration is done by using a 1:2 lever, making sure the upper plate in Figure 3.2b makes half the movement of the lower plate. Implementation of such a lever can be represented schematically as done in Figure 3.3.

![1:2 Lever](image)

**Figure 3.3: 1:2 Lever**

### 3.1.2 Basic design variations

In the early stage different configurations of the concept need to be compared. All of them rely on the same principle as suggested above, but all have a slightly different placement of the various components. Figure 3.4 shows three different designs.

![Different designs](image)

**Figure 3.4: Different designs**

In a first attempt to make sure the movement of the needle is perfectly straight, use has been made of two dual parallelograms. Setting them at an angle of 180 degrees with respect to each other, as seen in Figure 3.4a, will make sure the only movement that is possible is a straight line; any other motion or rotation will be suppressed. The use of a lever to realise a 1:2 motion of the different parts has become obsolete this way. Downside of this design is the fact it is over-determined, more degrees of freedom are fixated. This causes unwanted stresses and will possibly introduce hysteresis in the system. Therefore this option is dismissed and the design as shown in Figure 3.4b emerges. Here the 1:2 motion is realized by an additional lever connected at the end and at half the length, thus accomplishing a 1:2 motion. In an attempt to reduce the size of the
design, option c has emerged. Here the needle is placed inside the guiding mechanism, not only reducing the size but also realizing a perfect position for the motor applying the force at the mid centre of the leaf spring configuration. This is the ideal position to avoid the occurrence of extra loading components on the leaf springs [11].

3.2 Aerostatic guidance

An alternative frictionless guiding mechanism can be provided by aerostatic bearings. This would ideally eliminate the friction in the setup and no force is required to sustain a displacement as with the leaf spring configuration. This section will go over the design of such an apparatus and will discuss the points of interest.

3.2.1 Eliminating the two stage actuator

In the leaf spring alignment it was necessary to divide the actuation into two stages because of the limited displacement ability of the leaf springs. When using air/helium bearings this problem no longer arises, maximum movement can easily be 20 mm or more. With this range of motion possible, less stringent requirements can be set on the x – y guidance and more irregularities can be dealt with by the fine stage actuator. The basic design of such a configuration is shown in Figure 3.5. Gas is supplied trough the outer shell, filling a room around the mid-section of the moving body. This body is manufactured in such a way that trough holes in the middle the needle tip is supplied with gas. Of course bearing of the system is needed. This is accomplished by letting the gas flow trough several holes near the outside, supplying the upper and lower bearings with gas. This gas will form a layer between the moving body and the outer shell, providing bearings for the system. For correct operation a restriction should be added in the needle tip supply route. This restriction will make sure that enough pressure is build up in the bearing surfaces.

![Figure 3.5: Air bearing design schematically](image)
3.3 Comparison

After summing up different options for a guiding mechanism in z-direction, evaluation should be done in order to choose the best suitable option. Important is to keep in mind that research on the plasma needle is still in a very early stage and above all testing is important. Therefore the guiding mechanism should be carefully considered, but it should not be the main issue right now. An easy to manufacture and proven design is required to be able to begin testing as soon as possible. Air bearings require a small tolerance between the different parts to work and this calls for high precision manufacturing. Furthermore there is little known about bearings supplied with helium. Taking this into account the leaf spring alignment is the best suitable option at this point. For future applications the other design options should be carefully examined, as they can possibly offer advantages over the leaf spring alignment, especially when the treatment area increases. With a larger treatment area the required z-motion increases, which would result in larger leaf springs. The following paragraph will contain further details on the leaf spring option, in order to get an idea of the forces and sizes.

3.4 Leaf spring alignment in more detail

As mentioned in the previous paragraph the leaf spring design is chosen and first of all an impression of the required size of the leaf springs is given. This is done by using the formulas stated in “Constructieprincipes” [10]. These formulas are programmed in Matlab® and Figures are plotted to get insight in the various parameters as shown in Figure 3.6.

Both figures concern a single leaf spring; on the left side the thickness of the leaf spring is varied while keeping the length at a constant value, on the right side the length is varied while maintaining the same thickness. Each time the excitation is prescribed in the x-direction, perpendicular to the length of the leaf spring and resulting force is calculated and plotted against the variation. Material used in the calculations is spring steel, commonly used for leaf springs. The thickness of the leaf springs is chosen to be 0.1 mm, as small as possible to avoid the necessity of large actuator forces without endangering the ability to produce it. Furthermore 30 mm is selected as the length of the leaf springs, again to avoid large forces and to assure movement is within the elastic range. After this first impression calculations can be made regarding the various stiffness values. Yield stress, bending force and required actuator force will also be estimated. Two different forms of leaf springs are examined, a normal conventional leaf spring and a stiffened leaf spring. Results of this are shown in Table 3.1.

---

1 M-files can be found in appendix I
2 Formulas are added in appendix II
Table 3.1: Leaf spring data

<table>
<thead>
<tr>
<th></th>
<th>Conventional leaf spring (z = 30 mm)</th>
<th>Stiffened leaf spring (z = 35 mm)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{xx}$</td>
<td>$13,8 \cdot 10^3$ N/mm</td>
<td>$35,49 \cdot 10^3$ N/mm</td>
</tr>
<tr>
<td>$C_{zz}$</td>
<td>$153 \cdot 10^3$ N/mm</td>
<td>$115,87 \cdot 10^3$ N/mm</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>69 MPa</td>
<td>51 MPa</td>
</tr>
<tr>
<td>$F_k$</td>
<td>22,7 N</td>
<td>111,5 N</td>
</tr>
<tr>
<td>$F_{actuator}$</td>
<td>0,612 N</td>
<td>0,463 N</td>
</tr>
</tbody>
</table>

As can be seen the option with the thickened mid section has advantages over the other, a greater stiffness in the load direction and a smaller in the actuating direction. Result is a stiff system that can be moved with a minimum amount of force. Values in the table are related to one leaf spring only; the actuator force is associated with four leaf springs, the dual parallelogram construction.

Figure 3.7: Dual parallelogram guiding mechanism

The final design is shown in Figure 3.7, the rod for the motor connection is shown and a simple representation of the plasma needle. Use has been made of stiffened leaf springs. The needle will be redesigned in the next chapter.

¹ With thickened leaf springs $7/6 \times$ length is often used [10]
3.5 Selection of an actuator

In the previous section calculations have been made in order to get a view on the required forces. For actuation a number of options are available. A previous report has already considered various options for the actuator: a piezoelectric actuator, a linear stepper motor, a DC motor and a voice coil motor. The piezoelectric actuator is unable to make a displacement as required. Disadvantage of the linear stepper motor is the high static friction of the system and the necessity to use a digital control system. The option of the DC motor is dismissed because of the rotational instead of translational movement, calling for an additional gear\(^1\). Therefore the voice coil motor is selected, having a force proportional to the applied current and the translational movement.

Some advantages of the voice coil motor:

- Direct drive linear actuator, no extra connections or gear required.
- Switching current means switching direction, thus allowing a simpler control by changing the sign of the supplied current
- Limited moving mass due to fact is has only one moving component
- No cogging\(^2\)
- No hysteresis

A voice coil motor is made up of two components, one moving and one fixed (Figure 3.9). Applying a current on the core of the moving member, a group of coiled wires in a tubular form, will result in movement with respect to the fixed member, a permanent magnet. These motors are produced in a wide variety of forms. A company manufacturing these kinds of motors is BEI Technologies INC. Using their catalogue\(^3\) and the requirement of a 20 mm stroke, the LA19-40-000A seems a good solution. This voice coil motor delivers a maximum stroke of 23 mm and delivers a peak force of approximately 9 N.

\(^1\) More information about the various actuators in “Design of Positioning System for the Plasma Needle Probe” [8]\n\(^2\) The cyclic physical resistance felt in some alternator designs from magnets passing the coils and gaps in the laminates.
\(^3\) Catalogue is supplied in Appendix III

Figure 3.9: Voice coil motor
3.6 Conclusion and recommendations for x-y guidance

A leaf spring alignment as proposed above is a proven design and used in various high precision and demanding applications. In order to obtain reliable test data reproducible experiments are needed. Because of the frictionless guiding mechanism, the dual parallelogram leaf spring arrangement, hysteresis is almost absent and therefore reproducible tests are possible. Ultimately the plasma needle is to be used on humans and to this end reliable test data is an absolute necessity. Therefore the leaf spring guiding mechanism could serve well for the plasma needle.

Still only the z – movement is described in detail and the x – y movement has been left out. For this movement a standard H – bridge (Figure 3.8) can be used equipped with for example spindle for movement. Guidance in this direction is less influential as the z – probe can deal with small disturbances and speed in other than z – direction is slow in comparison.

Figure 3.8: Total setup schematically
4. Design of the plasma needle

After choosing a guiding mechanism the plasma needle should be carefully examined. A plasma needle has been manufactured, with the sole purpose of testing in mind. Virtually no considerations are made regarding the design of the needle itself. At present the apparatus is heavy and the connections for the electrical wire and the gas supply are not ergonomically positioned as seen in Figure 4.1. In the following section a design for the needle tip will be given, which will be directly applicable to the design of the guiding mechanism. At the end a suggestion for a handheld version of the needle will be provided, using the same principles as in the automated plasma needle.

![Current plasma needle](image)

**Figure 4.1: Current plasma needle**

4.1 The needle tip

If power to the plasma needle is increased for a moment and then returned to its old value, the matching network changes¹. This is thought to be caused by the heating of the needle. To reduce this influence the metal wire, or needle, can be shortened. Coax cable that is used to connect the power supply to the needle will cover most of the distance and only the very tip of the needle will be made out of metal.

Another point of interest is the generated heat at the tip of the needle where the plasma forms, contact with the skin causes damage and should therefore be avoided. One way to make sure the metal tip never touches the skin is to make sure the plastic housing covers the needle in total. This way the cover will touch the skin instead of the warm metal tip, if by accident contact is made. After treatment the plasma needle should be sterilized, even though the plasma kills most of the bacteria. To avoid having to disinfect the entire setup disconnection of the tip is desirable. This way no big machine is needed to make the needle tip sterile, but the tip can be disconnected and disinfected separately from the setup. A lay-out as shown in Figure 4.2 is suggested.

---

¹ A so called matchbox is developed to make the setup more power efficient and to be able to measure forward power without disturbance. In Van der Laan's study more detailed information is available [4].
Figure 4.2: Plasma needle tip lay-out

Thread is added to make the connection and a metal tip much like the one used in a BNC-connector is added to supply power to the plasma needle tip. A wire will run through the outer plastic shell to connect the connector tip to the plasma needle tip.

For connection of the needle tip as shown in Figure 4.2 to the gas- and power supply an intermediate body is needed. This will make linking of the two possible while maintaining the option to disconnect the needle tip. Another advantage of this setup is the possibility to connect a different kind of needle tip for different applications. The plasma needle tip can be attached by screwing it on to the intermediate body. This intermediate body can now be added to the guiding mechanism to obtain the total plasma needle setup. The wire for power and the tube for the gas supply can be integrated in the leaf springs. Care should be taken when placing these wires, they should be as free as possible to move and in no way restrict the movement of the guiding mechanism.
4.2 Suggestion for research concept
Research is vital and other institutions have shown interest in testing the plasma needle, therefore a sellable concept is needed. This solution should be easy to handle and above all be as simple and efficient as possible. Taking the needle tip with thread as the base design, a connection is needed between this and the gas- and power supply. In the automated design an intermediate body, similar to the one shown in Figure 4.3, is used for this purpose. A small modification will make it suitable for this design too. Figure 4.3 shows a design for the proposed body.

![Figure 4.3: Connection body](image)

A helium supplying tube large enough to house a small coax cable is chosen. This way the coax cable is hidden inside the gas supply cable, reducing the hassle with two different incoming cables. The intermediate body can be attached to both sides of the tube making sure the power supply is centred and connection can be established. Now a connection between the power and gas source can be made in much the same way as between the needle tip and the tube. In fact, a system controlling the flow of the gas and the power feed can be designed in such a way only helium will be connected to it. If this integrated system uses a coupling mechanism as suggested before, an all-in solution could be offered. This would mean supplying the plasma needle, the connecting tube and the power supply and gas controller.
5. Conclusion and recommendations on further research

Designing a guiding mechanism is a challenging task, not much information is available to start from. After getting a clear view on the research done in the past, new ideas arise. Chapter 1 gives a summary of past work. Design specifications were given thereafter. These helped to obtain the designs as given in chapter 3. Considering the various options, the leaf spring design was chosen to serve as guiding mechanism. Details on this design show the choice of actuator and give an idea of the dimensioning. Furthermore suggestions were made for an x – y guidance. However research should continue on the subject of guidance as future (bigger) applications might require another approach and it is not certain that this design is still the best available option.

In all the design the rotations are left out, for now that is acceptable, but treating a larger area it may be necessary to control the angel of the needle with respect to the skin. Ideally the plasma needle is oriented perpendicular to the skin, but problems arise trying to accomplish this. First of all the plasma follows the shortest path to the skin and this is not necessarily the patch alongside the z – axis of the needle. So an optical solution, where a lens tracks the plasma beam and adjusts the angle of the needle in order to line the plasma needle with the plasma beam, will not necessarily mean the needle is perpendicular to the skin. Of course perfectly at a 90 degree angle is not required, however contact between the needle and the skin should be avoided. Research on this subject should be done; how measurement of the angle is possible and with what accuracy should the angle be controlled.

Following a path on the skin surface using the position of the needle tip as reference may cause overlap due to the fact plasma follows the shortest path to the skin. Worst case would mean some spots are treated twice while other spots will not be treated at all. Present speed of the treatment will not cause this to be a problem, but speeding up the process in the future will.
Bibliography


Appendices
I. M-file Leaf springs

% Uitrekenen van bladveervariaties
clear all
close all
clc

gewenste parameters
Totaal_uitwijking = 2*10^-3;
u = Totaal_uitwijking/2; % gebruik dubbel parallellogram

% Rekening houden met helft van de uitwijking
u1 = u/2; % voor gebruik in EF
u  = u/2;

l = [10:0.1:50]*10^-3; % lengte bladveer
b = 40*10^-3; % breedte bladveer
d = 0.01*10^-3; % dikte bladveer

u = u/2 ; % halve bladveer geeft halve uitwijking
l = l/2 ; % halve bladveer geeft halve lengte

% Gegevens verenstaal
E      = 210*10^9;
svloei = 1000*10^6;
rho    = 7830*10^3;

% Schatting laagste EF
w = 2.1/u1 * svloei / ( sqrt(E*rho));
w
Kracht_totaal = [];

for n=1:length(l);
    I = (b * d^3)/12;
    Kracht_helft = (u*3*E*I)/(l(n)^3);
    Kracht = Kracht_helft*2; % enkele bladveer
    Krachttot = Kracht * 4;
    Kracht_totaal = [Kracht_totaal,Krachttot];
end
Kracht_totaal;

plot(l*10^-3,Kracht_totaal)
title('Variatie lengte in [mm] tegen kracht [N]','FontSize',16)
xlabel('Dikte bladveer in mm','FontSize',16)
ylabel('Kracht in Newton','FontSize',16)
II. Formulas

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E Modulus</td>
<td>207</td>
<td>GPa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>1000</td>
<td>MPa</td>
</tr>
<tr>
<td>Density</td>
<td>7830</td>
<td>Kg/m³</td>
</tr>
</tbody>
</table>

Leaf springs

Leaf spring without thickened mid section

Leaf spring with thickened mid section

Figure: Leaf springs

Leaf spring without thickened mid section

\[
C_{xx} = \frac{E \cdot t \cdot h}{l} \quad C_{zz} = \frac{E \cdot h \cdot t^3}{l^3} \\
\sigma_y = \frac{3 \cdot E \cdot t \cdot z}{l^2} \quad F_k = \frac{4 \cdot \pi^2 \cdot E \cdot I}{l^2}
\]

Leaf spring with thickened mid section

\[
C_{xx} = \frac{3 \cdot E \cdot t \cdot h}{l} \quad C_{zz} = 1.2 \cdot \frac{E \cdot h \cdot t^3}{l^3} \\
\sigma_y = \frac{3 \cdot E \cdot t \cdot z}{l^2} \quad F_k = \frac{36 \cdot \pi \cdot 2 \cdot E \cdot I}{l^2}
\]
### III. Voice coil motors

<table>
<thead>
<tr>
<th>Actuator No.</th>
<th>Continuous Stall Force (oz)</th>
<th>Stroke (± in)</th>
<th>Total Stroke (inches)</th>
<th>DC Resistance (ohms)</th>
<th>Force Sensitivity (oz/amp)</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA05-05-000A</td>
<td>11.35</td>
<td>0.02</td>
<td>0.04</td>
<td>4</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>LA08-10-000A</td>
<td>6.5</td>
<td>0.08</td>
<td>0.16</td>
<td>1.2</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>LA10-08-000A</td>
<td>9.7</td>
<td>0.1</td>
<td>0.2</td>
<td>9.9</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>LA10-12-027A</td>
<td>16.7</td>
<td>0.18</td>
<td>0.36</td>
<td>11</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>LA12-17-000A</td>
<td>56</td>
<td>0.15</td>
<td>0.3</td>
<td>2.8</td>
<td>26.4</td>
<td></td>
</tr>
<tr>
<td>LA13-12-000A</td>
<td>25.6</td>
<td>0.125</td>
<td>0.25</td>
<td>17.1</td>
<td>35.2</td>
<td></td>
</tr>
<tr>
<td>LA13-30-000A</td>
<td>18.24</td>
<td>0.7</td>
<td>1.4</td>
<td>4.6</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>LA14-17-000A</td>
<td>25.6</td>
<td>0.2</td>
<td>0.4</td>
<td>6.5</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>LA15-16-020A</td>
<td>41.6</td>
<td>0.2</td>
<td>0.4</td>
<td>4.4</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td>LA15-16-024A</td>
<td>88</td>
<td>0.125</td>
<td>0.25</td>
<td>4.7</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>LA15-26-000A</td>
<td>42</td>
<td>0.5</td>
<td>1</td>
<td>9.1</td>
<td>31.7</td>
<td></td>
</tr>
<tr>
<td>LA15-65-000A</td>
<td>68</td>
<td>2</td>
<td>4</td>
<td>5.4</td>
<td>33.6</td>
<td></td>
</tr>
<tr>
<td>LA16-27-000A</td>
<td>50</td>
<td>0.12</td>
<td>0.24</td>
<td>3.3</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>LA17-28-000A</td>
<td>102.4</td>
<td>0.3</td>
<td>0.6</td>
<td>6.7</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>LA18-12-000A</td>
<td>54.4</td>
<td>0.12</td>
<td>0.24</td>
<td>2.6</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>LA19-40-000A</td>
<td>30.56</td>
<td>0.9</td>
<td>1.8</td>
<td>2.85</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>LA24-20-000A</td>
<td>162</td>
<td>0.325</td>
<td>0.65</td>
<td>2.2</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>LA25-42-000A</td>
<td>310</td>
<td>0.5</td>
<td>1</td>
<td>2.4</td>
<td>76.8</td>
<td></td>
</tr>
<tr>
<td>LA30-43-000A</td>
<td>588.8</td>
<td>0.5</td>
<td>1</td>
<td>2.6</td>
<td>112</td>
<td></td>
</tr>
</tbody>
</table>