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IMPROVEMENT AND FIELD TESTING OF A SOLAR POWERED LIFT AND CARRY TYPE MILKING MACHINE

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Final Report

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1.0 Introduction/Background

Manual milking is a tiring operation and now a day it is difficult to find skilled manual milkers. Further a manual milking is difficult in medium and large scale commercial dairy farms. Therefore medium and large scale farmers are using milking parlors or milking machines.

Figure 1 shows the Sri Lankan cattle farms by herd size (relevant data are listed in table 1) according to the department of census and statistics, Sri Lanka (http//www.statistics.gov.lk/agriculture/index.html accessed 09/03/2011). Milking parlors are suitable for farmers having over 20 cows. From 10 to 20 cows a milking machine with two clusters would be suitlable. Farmers having 5 to 10 cows cannot afford for a milking machine, considering the price of portable milking machines available in the market. Further these milking machines are driven by electric motors and needs mains grid supply. Otherwise an electricity generator is required. Most of the Sri Lankan small scale cattle farmers do not have electricity and even though they have electricity in their homes, the cattle barns are not wired and located in a distant place to the home. Therefore not having electric supply in barns is a major constrain in using milking machines in Sri Lanka.

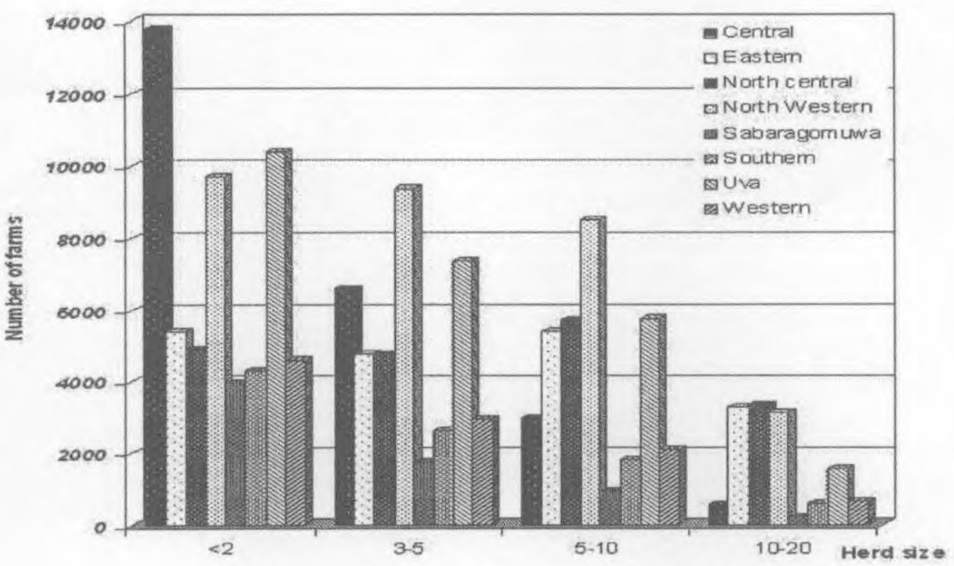


Figure 1. Cattle farms by herd size in Sri Lanka

Table 1. Cattle farms by herd size in Sri Lanka.

Herd size	Provinces							
	Centr al	Easter n	North centra l	North Wester n	Sabarag o- -muwa	Souther n	Uva	Wester n
<2	13791	5402	4880	9709	3980	4312	10390	4600
3-5	6603	4748	4727	9378	1746	2638	7368	2949
5-10	2972	5379	5712	8496	935	1808	5767	2104
10-20	549	3313	3366	3147	235	576	1585	662
>20	100	2970	2298	1079	62	384	386	121

Figure 2 shows a conventional milking machine available in Sri Lanka. The conventional milking machine uses an electric motor driven vacuum pump with a separate vacuum cylinder which is connected to the milk collecting can to maintain a continuous vacuum. A mechanical devise provides the pulsation to extract milk from the teats. Conventional portable milking machines are on wheels and are unable to lift and carry by a single person.

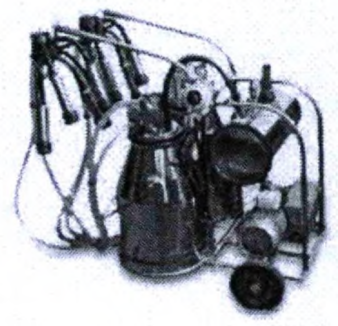


Figure 2. Conventional Portable Milking Machine

The main disadvantages of the conventional milking machines are;

1. The requirement of a main grid power source to power the machine. A majority of small holder milk producers in Sri Lanka do not have main grid power in their cattle sheds.

2. The large amount of power (over 1000W) consumed by the conventional milking machine to build up the vacuum required for machine milking.

3. Limited portability due to the heavy weight (cannot lift and carry) of the machine and also the high cost of conventional milking machines make its use limited in cases where a large number of farmers having one or two cows.

Apart from the above mentioned disadvantages, the limited applicability of a conventional milking machine under small scale producers increases the risk of microbiological contamination of milk by the process of hand milking. Thus the keeping quality and hygienic aspect of milk production needs a solution. Most often there is a tendency by unscrupulous small holder producers to use preservatives harmful to health to increase the keeping quality of milk.

Therefore to overcome above limitations of a conventional portable milking machines, a battery powered lift and carry type (the whole machine weighs less than 10kg including 10 liter milk can) milking machine (Model 1) was designed and tested. The machine consumes lower energy (60W) compared to a conventional milking machine (over 1000W) of similar capacity. Battery charging can be done by a 10W photo-voltaic cell or by a low power (1A) AC battery charger. Figure 3 shows the developed lift and carry type milking machine with the solar cell.

Figure 3. Lift-and-carry type milking machine (Model 1).

Two patents were applied for the milking machine and the teat-cup assembly respectively (Patent Numbers-).

Identification of the problem and justification.

Although the developed solar powered lift and carry type milking machine is tested for the functionality there are several improvements and tests to be carried out before introducing to the farmers.

Major concerns were,

1. Durability of machine parts.
2. Difficulties faced by a farmers during operation at farm level.
3. Udder health using the milking machine.

Therefore this study was focused on the above mentioned concerns and develop technologies necessary to overcome above problems before introducing to the farmers. After this study investigators believe that machine should be ready for mass production to introduce to the farmers.

2.0 Objectives

The objective of the study is to develop technologies necessary to improve the presently developed solar powered lift and ca milking machine (Model 1) so that it can be introduced to the dairy farmers.

There are three specific objectives derived from the major concerns of the existing milking machine.

1. Evaluation and testing the machine under farm conditions and improving the **durability of parts.**
2. Identifying difficulties faced by farmers using the developed milking machine and improving its **ergonomics** to suit farmer's conditions.
3. Evaluation of **udder health** of cows in using the developed milking machine and make necessary changes to the machine to improve the udder health.

3.0 Description of the work (against the proposed project design, work plan etc.)

Farmers feedback is the most important factor on achieving the final objectives. Therefore, three milking machines (Model 2) were fabricated at the Department of Agricultural Engineering and evaluated for the three specific objectives, the durability, ergonomics and udder health. With continuous monitoring and evaluation, while they are being used by the selected farmers, investigators started working on necessary improvements. The improvements were included in the milking machines (Model 2) and carry on field testing with the same farmers until appropriate acceptable technology was achieved. Two patents were applied for the naval technologies generated on the concept and the new teat cup design. Model 3, which includes all the developments was fabricated and tested and is ready to be marketed.

Brief description of research/work carried out

1. **<u>Improvement of parts</u>**

Improvements for the following parts were carried out based on the experience of the previous model (Model 1).

1. Vacuum mechanism- Previously developed model has a DC driven geared mechanism for driving the vacuum piston. After testing the machine for several hours it has been noticed that this mechanism consumes more power and has a problem of wear. Then a new mechanism (Figure 4) was developed with direct drive DC motor and proved that it consumes 60% power than the previous and with less wear. This is a great achievement on power consumption and durability. Therefore the presently adopted mechanism for vacuum could be utilized without many modifications for the production of milking machines commercially.

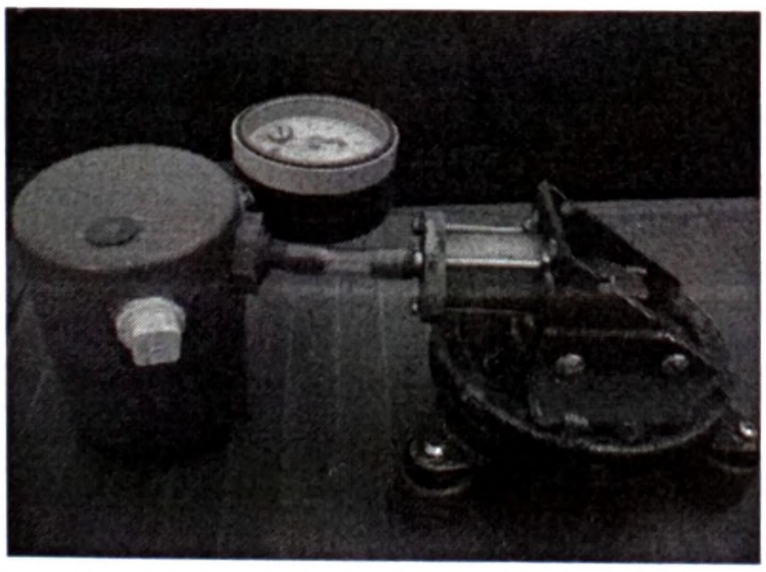


Figure 4: Newly developed vacuum mechanism

2. Teat cups and pulsation- Major modifications were done to the pulsation line assembly where it could be reproduced easily without molding. Further the pulsation valve was installed directly on the teat cup (Figure 5) so that the vacuum loss during pulsation is less. This saves electrical energy and helps in increasing the battery life.

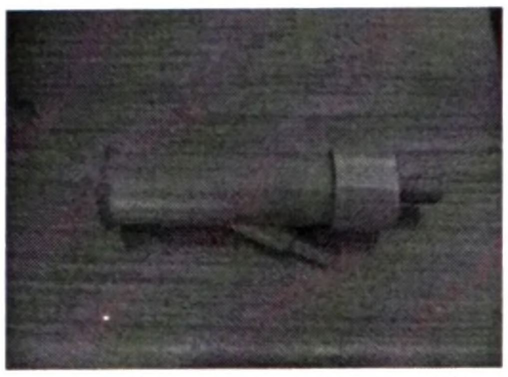


Figure 5: Improved teat cup assembly

3. Development of the commercial scale milking machine

After interviewing dairy farmers it was understood that some needs total mobility of the machine including the solar cell. As an example, their cows are here and there and there is no fixed place for milking. The Model-2-1 is for them.

The second type is for farmers having proper place for milking and needs larger capacity battery as their herd size is larger and may be two milking machines are needed. They have a place to fix a battery and the solar cell in their cattle barn. The Model-2-2 has the advantage of lower weight (external battery) and easy handling.

Model-2-3 is for farmers having permanent cattle sheds and have mains electricity too. They can use either an external battery charged with a mains supply of can run the machine directly on mains electricity (12V DC stepped down).

Figure 6. Three Models of milking machines (Model 2).

The first year of the project mainly focused on the first two objectives, the durability of parts and improvement of mechanisms. During the first 6 months a durable vacuum mechanism was developed. This mechanism was improved adding few more features, namely a non-return valve to hold the vacuum without leaking through the valves of the piston mechanism and improving air movement in to the cylinder by using large diameter valves with acrylic flaps (Figure 7).

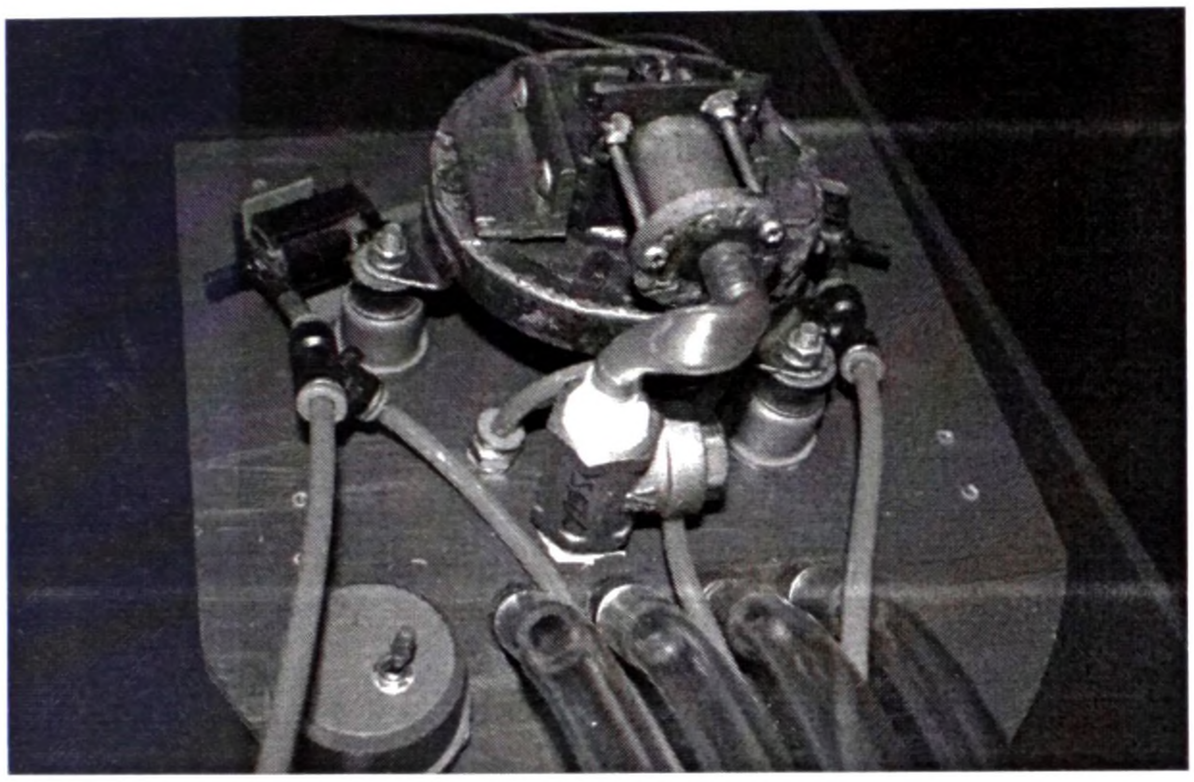


Figure 7. Improved vacuum mechanism.

The vacuum mechanism was tested for its wear and tear, need for lubrication and generation of heat. Table 2 summarizes the data obtained in this test.

Table 2. Heat generation and lubrication testing for improved vacuum mechanism.

Time (min.)	Temp. of the cylinder (C)	Current at ½ atm pressure (A)	Battery voltage (V)	Need for lubrication	Noise (db)	Remarks
10	40	5.5	12.8	No	30	Low vibration smooth running
20	43	5.1	12.7	No	30	Stable in operation
33	50	4.9	12.7	No	30	Stable in operation
40	51	5.0	12.5	No	30	Stable in operation
50	55	4.8	12.5	No	30	Grease melts and lubricate well
60	55	4.8	12.4	No	30	Cylinder lubricates well
70	55	4.7	12.0	No	30	Grease does not disappear

According to the results the vacuum mechanism is capable of running under commercial scale. The long term testing of the machine was performed and found the there is no need of replacing any moving parts. The vacuum mechanism is the most important part of this machine as it determines the efficiency of the machine and overall performance. Therefore much of the effort was for the vacuum mechanism and finally a low power consuming durable vacuum mechanism was developed.

Two main concerns in udder health using the milking machines are the infection of mastitis (microbiological) and the swelling due to vacuum (physical). Since we are maintaining the same suction as used in commercial milking machines with similar pulsation rates, the possibility of swelling and physical damage to the udder tissues is not expected. The problem of mastitis is the main yield-reducing-factor in all over the world and the whole milk industry is seeking better mechanisms of mitigating spread of mastitis through milking machines. The problem arises with liner slipping where a teat-cup slips during machine milking. This will expose one teat cup to atmospheric pressure and the milk in the cluster (cluster has a mixture of milk from all four teats) enter in to the other three teat-cisterns and if one teat has mastitis this will contaminate all three teats. So far there is no mechanism in avoiding this contamination due to liner slip in any of the milking machines.

This problem was effectively addressed in this design after searching for possibility of preventing mixing of milk from teat cups before milk goes in to the milk tank. The possibility of having shorter milk tubes were the key in achieving separate milk tubes ending at milk tank starting from individual teat-cups. After doing several tests with the conventional type arrangement of milk lines with a cluster fixed to the milking machine revealed that this milking machine needs only 45cm milk line to operate the machine comfortably. This is a great achievement in this study and the new design has no cluster instead has separate milk lines so that there is no way that milk from one teat mixes with the other before going in to the milk tank. This arrangement not only preventing spread of mastitis but provides better cleaning of teat cups and milk tubes simply by removing and brushing with soap (Figure 8).

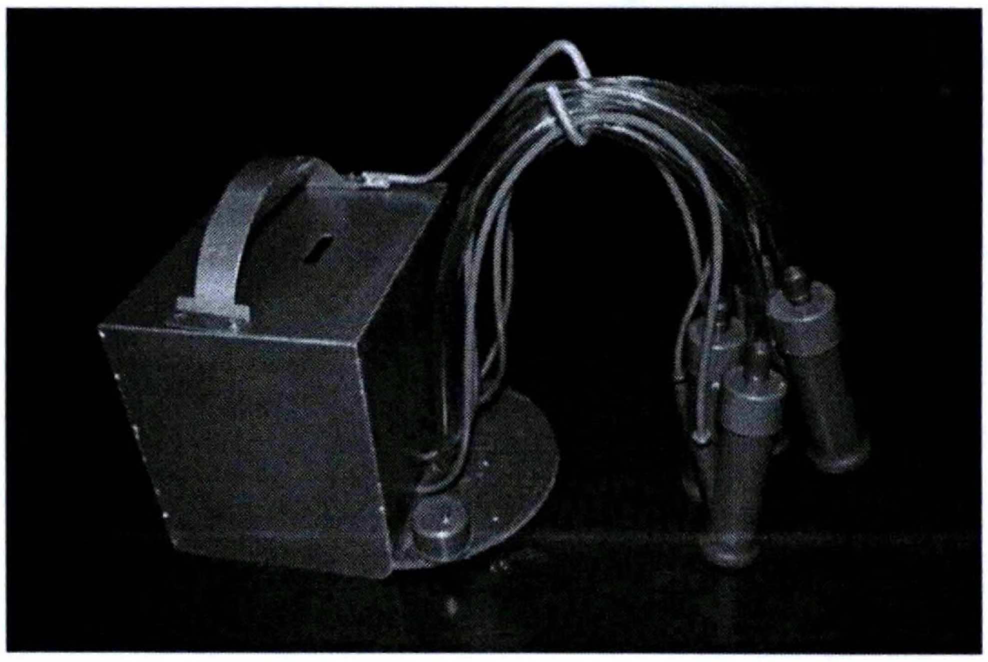
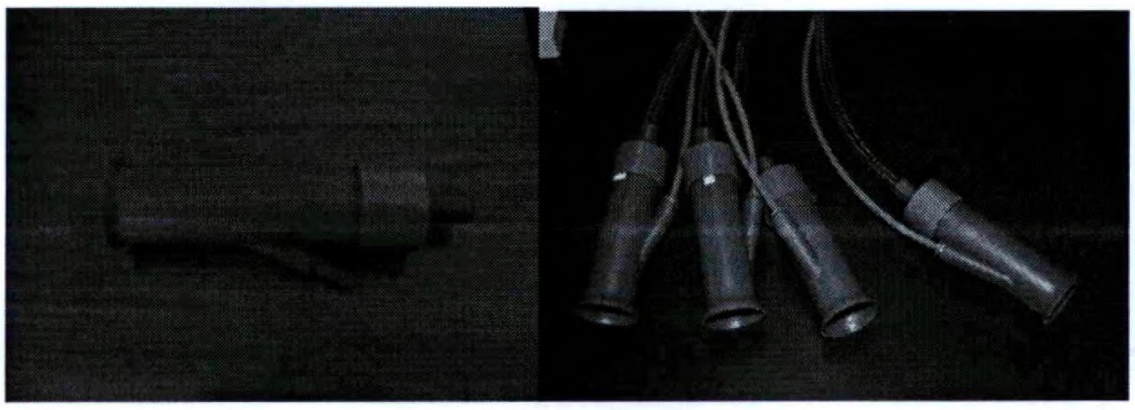


Figure 8. Milking machine with direct milk tubes (no cluster)

An improved teat cups were developed in such a way that the pulsation line is fixed in one piece to the teat cup. This was further improved by making the pulsation line with high pressure polyurethane (PU) components available in the market with quick-couplings (Figure 9).



(a) Previous design (b) New design with PU tubes and quick couplings

Figure 9. Improved teat-cups

Pulsation

The pulsation mechanism was re arranged using, electric solenoids, PU tubing and fittings with quick-couplings (Figure 10). This arrangement is more durable compared to the previous method used and also assembling and maintenance is easy. PU pneumatic components are freely available in Sri Lankan market.

Figure 10. Arrangement of pulsation mechanism with PU pipes and fittings

Two pneumatic solenoid valves normally used in vehicles for operating different components in the engine were used for pulsating the teats. Two teats pulsate at a time and the milking and the resting periods can be changed with the variable resistors provided in the controller. There is a difficulty in finding these types of valves in large numbers for commercial production and presently looking for an alternative.

Pressure and pulsation control

Pressure regulation was done by ON-OFF control of the vacuum pump using a microprocessor based control system (Figure 11). The pressure sensors used in this milking machine are shown in Figure 12. The 16F684 microprocessor was used for controlling the pressure and the pulsation. The programmer and the prototyping boards for programming and debugging are shown in Figure 13. They all bought for this study and are highly versatile components providing worlds high end technology with low price. This is the cheapest way of automating the system with higher accuracy and durability.

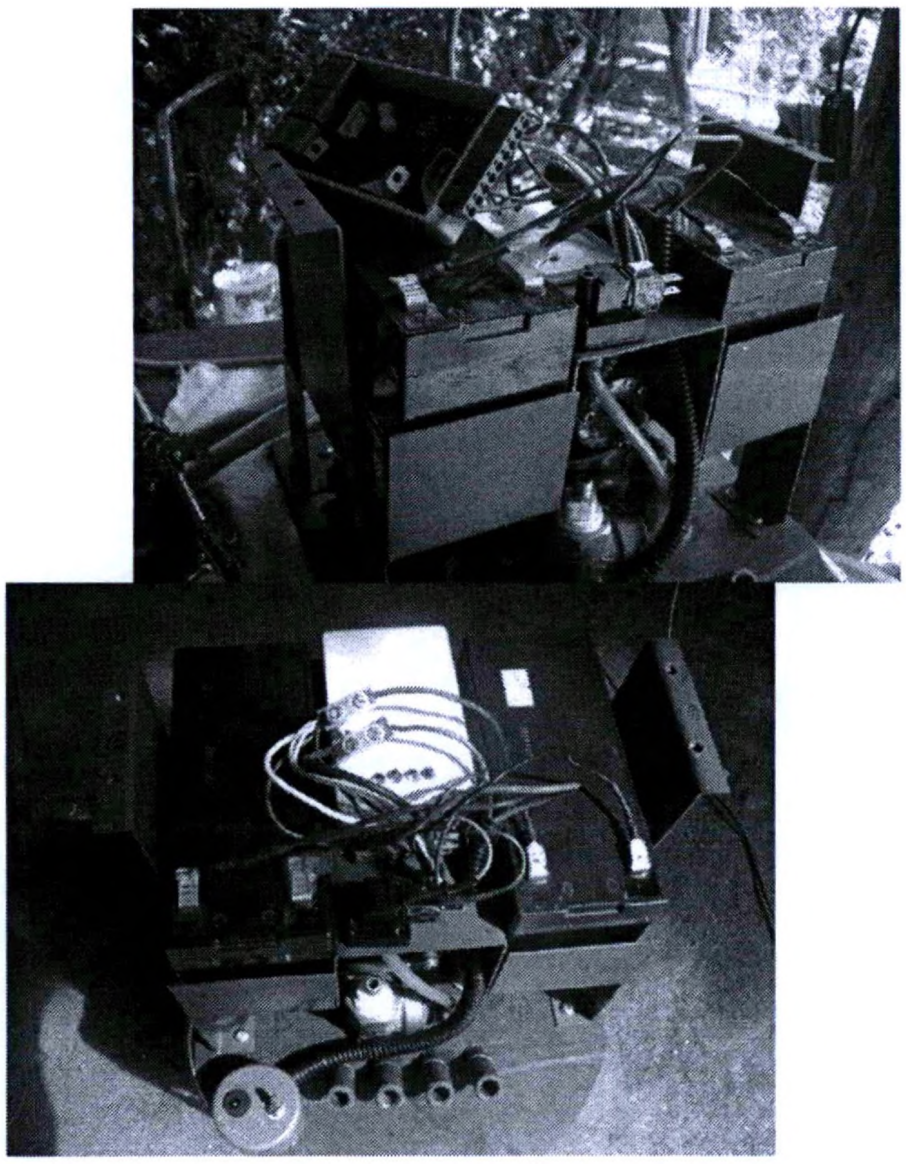


Figure 11. Control circuit and the wiring.

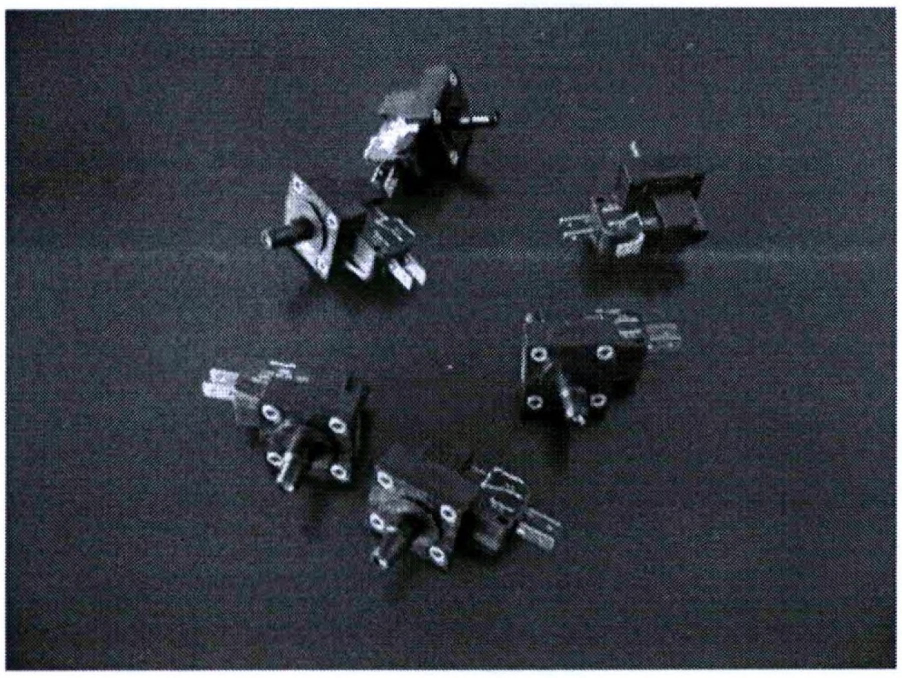


Figure 12. Pressure sensors used in the milking machine.

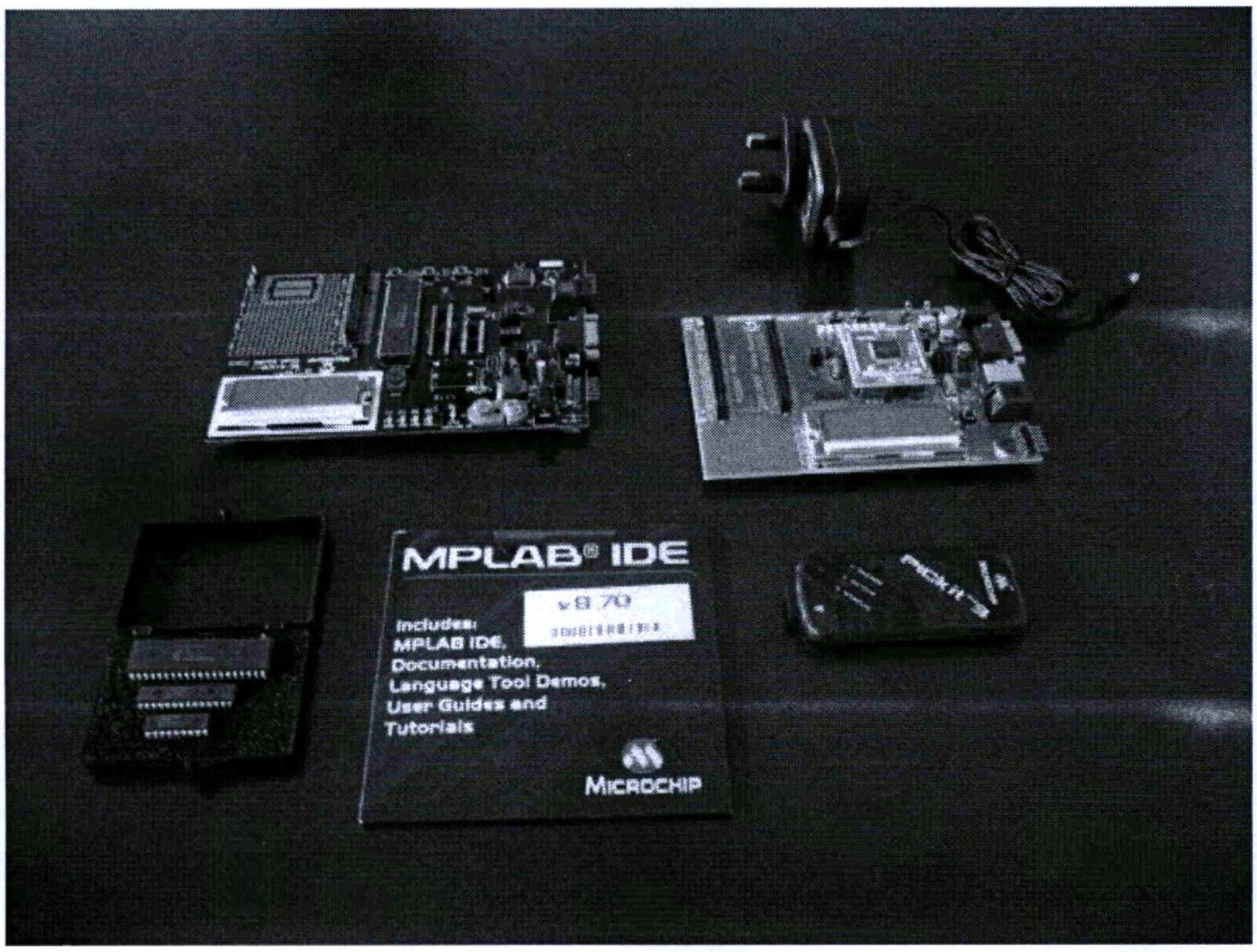


Figure 13. Programmer (PicKit3) and the development boards.

The Control Program

A control program for pressure regulation and pulsation was written in C language and is listed in the List 1.

List 1. Control program for the 16F684 micro processor.

```
#include <pic16f684.h>
/*
***********************************************************
*                    MILKING MACHINE                      *
*                                                         *
*                    K.S.P. Amaratunga                    *
*                    Department of Agricultural Engineering *
*                    Faculty of Agriculture               *
*                    University of Peradeniya             *
*                    SEPTEMBER 2012                       *
*                                                         *
*                    All rights reserved                  *
*********************************************************** *
PIC16F684 In-circuit Serial Programming with PicKit-3

                    *****        -    Vcc-1    14-Gnd -
                    ***** ICSP -      RA5-2    13-RA0 - ICSPDAT (AN0)        *****
                                 -    RA4-3    12-RA1 - ICSPCLK (AN1)        *****
        *****MCLR     -         RA3-4    11-RA2 -
  VAC PUMP ON/OFF    -          RC5-5    10-RC0 - On time VR1 (AN4)
        PULSE 1 ON/OFF   - RC4-6          9-RC1 - Off time VR2(AN5)
        PULSE 2 ON/OFF   -      RC3-7     8-RC2 - VAC SWITCH (OK/NO)
*/

__CONFIG(INTIO & WDTDIS & PWRTEN & MCLRDIS & UNPROTECT & UNPROTECT & BORDIS & IESODIS & FCMDIS);

int i, j;
int ONTIME, OFFTIME,on,off;              //          ADC read current

main()
{
  PORTC=0;
         PORTA=0;

         TRISC0=1; //
         TRISC1=1; // SETT VR2
         TRISC2=1; // SETI VR3

         TRISC3=0; // PULSE
         TRISC4=0; // VAC PUMP
         TRISC5=0; // ON/OFF

  CMCON0 = 7;          // Turn off Comparators

while (1 == 1)
 {
// ************************* Pulsation ***********************
RC4=1;

for (on=0;on<ONTIME;on++)
{
for (i=0;i<1000;i++)
         for (j=0;j<49;j++);
}

RC4=0;
for (off=0;off<OFFTIME;off++)
{
         for (i=0;i<1000;i++)
                  for (j=0;j<50;j++);
}
```

```
RC4=1;
for (off=0;off<OFFTIME;off++)
{
            for (i=0;i<1000;i++)
                        for (j=0;j<50;j++);
}
int i, j;
int ADCState = 0;          // Keep Track of ADC Operatio
int TEMP=0;                                                              //          ADC read temperature
int CURRENT=0;
int ONTIME, OFFTIME,on,off;                                   //          ADC read current

int SETT=0; //              - VR2
int SETI=0; //              - VR3

int C_ERROR=0;
int T_ERROR=0;
int TValue = 0;            //
int CUValue=0;             // Current Value
int RV2Value=0; // SETT by RV2
int RV3Value=0;            // SETI by RV1

int ad1=0;  // Flour temp
int ad2=0;
int ad3=0;
int ad4=0;
int ad5=0;

int CU1=0;  //Motor current
int CU2=0;
int CU3=0;
int CU4=0;
int CU5=0;

//********************** Vac. pump operation ****************
RC4=0; // vacuum pump 1/2 atm RC2=0 else RC2=1
if (RC2=0)
            {
            RC5=1;
            }
            else
            {
            RC5=0;
            }

} // elihw
} // End

int RV21=0; //SETT from RV2
int RV22=0;
int RV23=0;
int RV24=0;
int RV25=0;

int RV31=0; //SETI from RV3
int RV32=0;
int RV33=0;
int RV34=0;
int RV35=0;

main()
{
            NOP();
  PORTC=0;
            PORTA=0;

            TRISA2=1; //
            TRISC0=1; //
            TRISC1=1; // SETT VR2
            TRISC2=1; // SETI VR3
```

```
            TRISC3=0; // Air valve ON/OFF
            TRISC4=0; // Air valve CW/CCW
            TRISC5=0; // Feed grains ON/OFF

  CMCON0 = 7;          // Turn off Comparators
            ANSEL= 0b00110000;
/* ANSEL = 0b11111100;       // Just RA0 is an Analog Input
  ADCON0 = 0b10000001;     // Turn on the ADC
                 //  Bit 7 - Left Justified Sample
                 //  Bit 6 - Use VDD
                 //  Bit 4:2 - Channel 0
                 //  Bit 1 - Do not Start
                 //  Bit 0 - Turn on ADC
  ADCON1 = 0b00010000;     // Selemct the Clock as Fosc/8
            TRISA=0b000101;
*/

// System initialization

while (1 == 1)
 {

// OFF TIME VR1 (RV2 -AN4 (RC0) ****************

ANSEL = 0b00110000;
for (i=0;i<1000;i++);

ADCON0 = 0b00010001;
                        switch (ADCState)     // ADC State Machine
    {
                                    case 0:        // Finished, Start Next Sample
        GODONE = 1;
        ADCState++;
        break;
      case 1:          // Wait for ADC to complete
        if (!GODONE)
          ADCState++; // Sample Finished
        break;
      case 2:          // Save Sample Value in "ADCValue"
        RV2Value =  ADRESH;
                                              //RV2Value +=(ADRESH << 8);
                                              ADCState = 0;

        break;
    } // hctiws
// moving average
// RV25=RV24;
// RV24=RV23;
// RV23=RV22;
// RV22=RV21;
// RV21=RV2Value;
// ONTIME=(RV21+RV22+RV23+RV24+RV25)/5*2;

OFFTIME=RV2Value;
for (i=0;i<1000;i++);

// ONTIME VR-2 RC1 AN5 *******************************

// RV2 input
//ANSEL = 0b00010000;
ADCON0 = 0b00010101;
                        switch (ADCState)     // ADC State Machine
    {
                                    case 0:        // Finished, Start Next Sample
        GODONE = 1;
        ADCState++;
        break;
      case 1:          // Wait for ADC to complete
        if (!GODONE)
          ADCState++; // Sample Finished
        break;
```

```
case 2:         // Save Sample Value in "ADCValue"
   RV3Value = ADRESH;
                                                    //RV3Value +=(ADRESH << 8);
                                                    ADCState = 0;

   break;
  } // hctiws
// moving average
// RV35=RV34;
// RV34=RV33;
// RV33=RV32;
// RV32=RV31;
// RV31=RV3Value;
// OFFTIME=(RV31+RV32+RV33+RV34+RV35)/5*2;

ONTIME = RV3Value;
ONTIME=ONTIME*7;
OFFTIME=OFFTIME*7;
RC5=1;
for (on=0;on<ONTIME;on++)
{
for (i=0;i<1000;i++)
            for (j=0;j<49;j++);
}
RC5=0;
for (off=0;off<OFFTIME;off++)
{
            for (i=0;i<1000;i++)
                        for (j=0;j<50;j++);
}
} // elihw
} // End
```

The control program was continuously improved for the efficient operation of the machine based on the test results with different breeds and milk yield.

Batteries and the photovoltaic cell

Two 7AH 12V lead acid batteries were fixed in the Model-2 (Figure 14). A DC jack provided will charge these batteries and either a photovoltaic cell or an external battery charger can be used to charge these two batteries. Other two milking machines do not have batteries in it. Instead one is designed for an external (Large) battery for longer duration use. The capacity of the battery has not yet decided. After testing Model-1 with two batteries, the capacity for of the battery for the Model-2 will be decided. Model-3 does not have batteries at all. Instead it will work with the mains supply stepped down to 12 V DC using a transformer. This machine is for those who have electricity in the barn and want to save initial cost for batteries and photovoltaic cell.

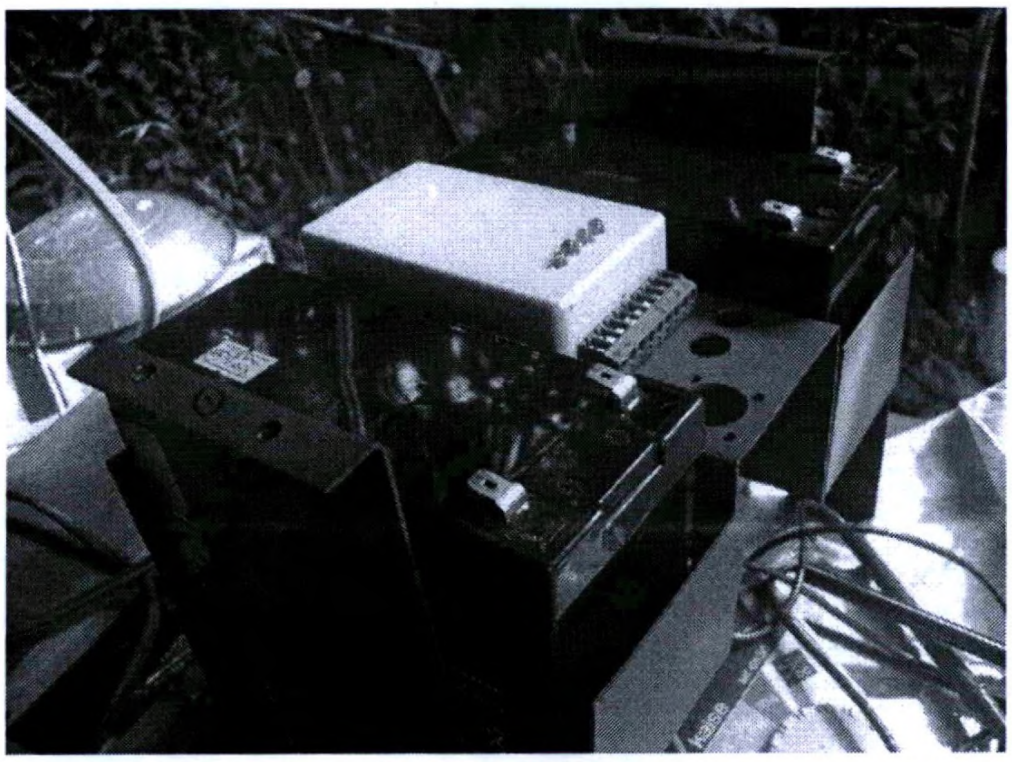


Figure 14. Two of 7AH 12V lead acid batteries placed inside Model-1

Six photo voltaic cells (three of 20W and three of 30W) were bought (Figure 15) for studying the capacity and requirement under different operational conditions. With these photovoltaic cells following combinations (Table of power will be tested for determining the capacity under different weather conditions.

Figure 15. 20W and 30W photovoltaic cells bought

Table 3. Total power with different combinations of the photovoltaic cell bought.

Photovoltaic cell combination	Total power
20 W	20W
30 W	30W
20+20W	40W
20+30W	50W
30+30W	60W
20+20+30W	70W
20+30+30W	80W
30+30+30W	90W
20+20+30+30W	100W
30+30+30+20W	110W
20+20+20+30+30W	120W
20+20+30+30+30W	130W
20+20+20+30+30+30W	150W

Bottom plate and the air seal

Bottom plate was made out of PVC which is food grade and have the advantage of easy machinability, no corrosion and durability. All the components were fixed to this base-plate and a rubber plate was pasted to the bottom of the plate to avoid any leaks through the mouth of the milking tank.

Assembly of the milking machine

All the parts of the milking machine were assembled in such a way that all the components housing in a single piece (Figure 16). On/Off switch and indicators (power, pressure, pulsation) are provided for the user. Machine should be kept on a milking can for milking. Milking can be of the capacity varying from 10 Liter to 20 Liter. The larger the can the longer the time to develop the necessary vacuum. It takes 30 seconds to develop ½ atm (the required vacuum pressure) with a 10 Liter milking can.

Figure 17 shows the Milking machine after fixing the cover and the teat-cups and placing it over a 10 Liter milking can and the Figure 18 shows all assembled three milking machines.

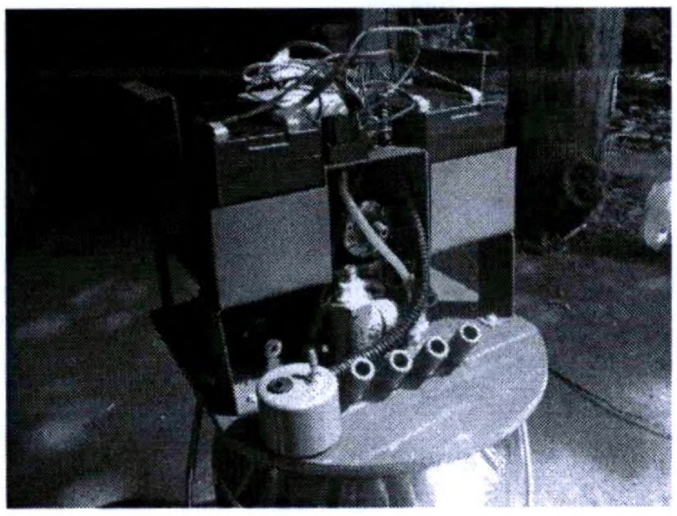


Figure 16. Assembly of components in to single unit (figure shows without the cover)

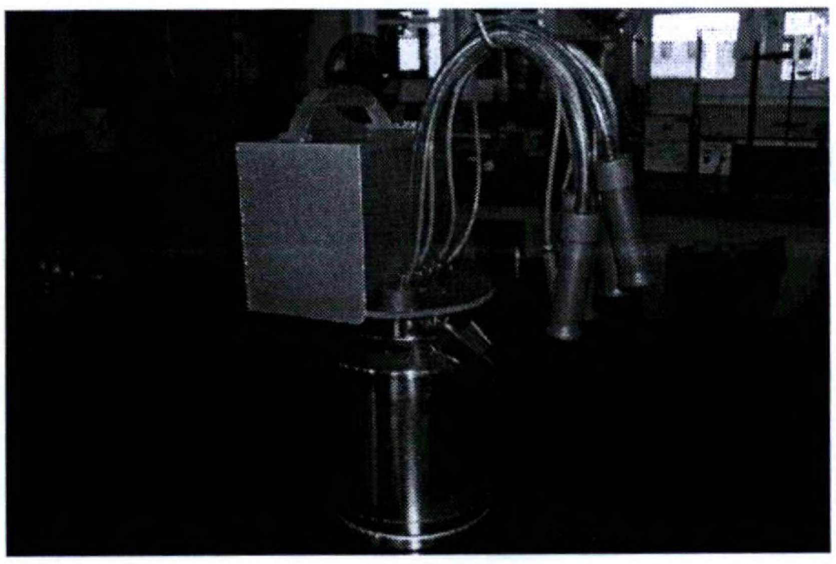


Figure 17. Complete milking machine with a 10 Liter can

Figure 18. All three types of milking machines assembled.

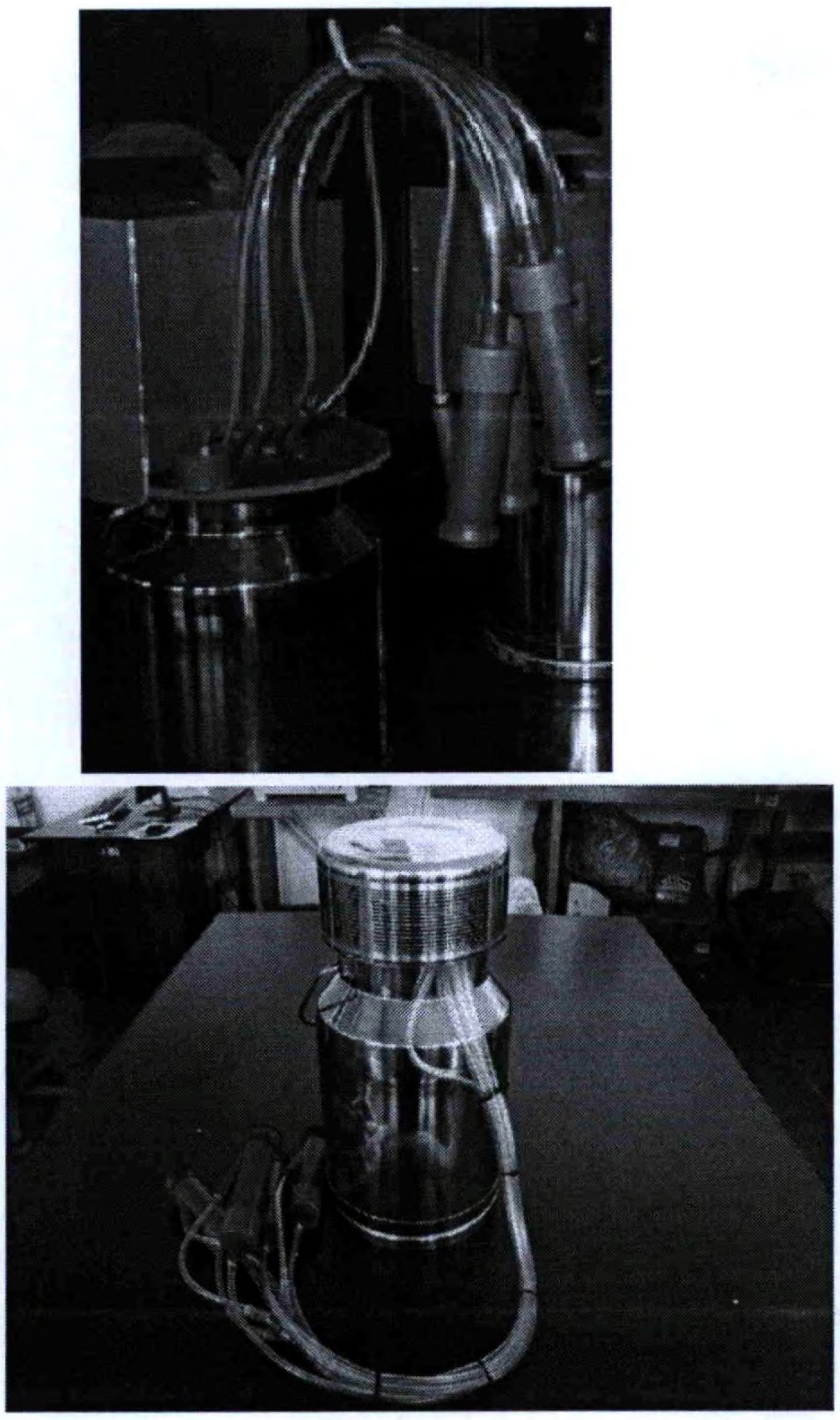
Further developments based on the previous model

Three milking machines developed were tested for its operation and ergonomics. Based on the results a new milking machine (Model 3), which is simpler in design and lower in cost (Figure 19 (b)) was designed and fabricated. The average current consumption of the new design was 2.7 ±.5 A compared to the previous model which consumes 4.97A. Therefore the new machine can run with D-type rechargeable Ni-MH dry batteries whereas previous models used Led-Acid batteries. This reduced the weight and the volume of the milking machine. Further the new design has less number of parts than the previous models (Figure 19). The air sealing mechanism was improved using an "O" ring and the PVC lid design, which ensures easy fixing and detachment of the machine from the milk tank. The new model is compact and light weight compared to the previous.

Several improved features of the milking machine (Model 3) are compared with the old machine (Model 2) in Table 4.

Table 4: Comparison of old and improved milking machine

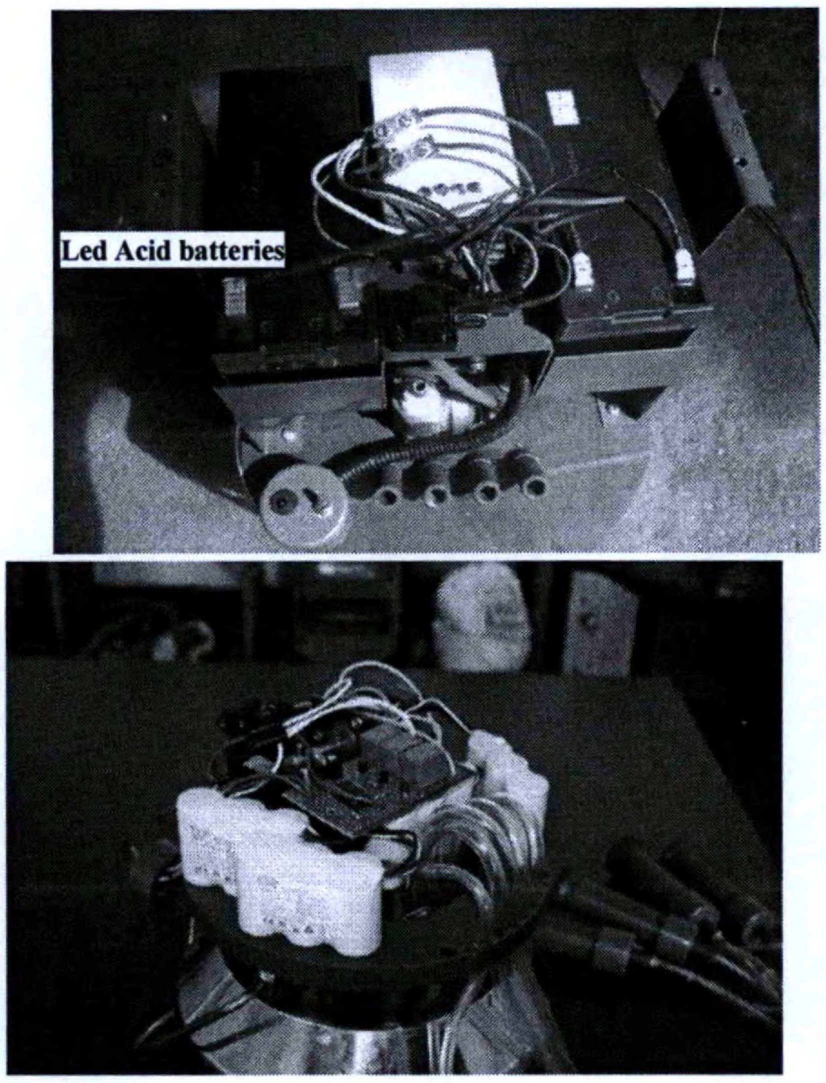
No	New machine (Model 3)	Old machine (Model 2)
1	Improved vacuum mechanism with three valves mounted on PVC	2 valves on metal
2	3.2 kg weight (Without milk can)	4.6 kg (Without milk can)
3	Direct coupling of milk and vac. tubes to the base plate	Tubes are connected using connectors to the base plate
4	2.7 A current consumption	4.97 A
5	3 valve vacuum system	2 valves
6	Ni-Cd Battery weight 1.1 kg	Lead-Acid Battery weight 1.8 kg
7	"O" ring sealing	Rubber plate sealing
8	Simple and less number of parts	Complicated
9	Low cost	High compared with the new machine



(a)

(b)

Figure 19: Old (Model 2) (a) and the improved (Model 3) (b) milking machine



Ni-MH batteries

(a) (b)

Figure 20: Inside view of the old (a) and the improved (b) milking machine

General test results of the Model 3

Several tests were carried out to test the functionality of the milking machine developed (Model 3).

Battery charging:

1. Battery charging current from a 10W solar photo-voltaic cell.
    1. Sunny day average - 0.55 A @ 12.71 battery Voltage
    2. Cloudy day average - 0.03 A @ 12.71 Battery Voltage
2. Battery charging with a 12V, 1A Battery charger - 0.6 A (Average @ 12.71V)

All the machine parts designing and construction were done in order to reduce power consumption of the machine.

Electrical power requirement:

Vacuum pump - 48 W

Pulsation unit - 6W

In a milking machine, the vacuum pump is the device, which requires high power compared to the other device. Therefor to reduce the power consumption, the working time of the vacuum pump should be minimized. Introducing electronic vacuum regulator and using comparatively small vacuum chamber helped to minimize the working time of the pump. The electronic pressure regulator turns off after the vacuum pump reach required vacuum level. In this machine, small vacuum level is reached quickly avoiding the continuous operation of the vacuum pump.

Machine was programmed to operate with 2 s milking phase and 1s resting phase and tested for vacuum generation and continuously operated for 4 hours and 15 min. Results revealed that it takes 30s to create 22 mmHg vacuum pressures.

New milking machine (Model 3) is simpler design and low in cost. The average current consumption of the new design is 2.7 ± .5 A compared to the previous model which consume 4.97A. Therefore the new machine can run with D type rechargeable Ni-MH dry batteries whereas previous model used Led Acid batteries. This reduced the weight and the volume of the milking machine. Further the new design has less number of parts than the previous models. The air sealing mechanism was improved using rubber plate and the PVC design, which ensures easy fixing and detachment of the machine from the milk tank. The new model is compact and light weight compared to the previous. In addition to that the whole machine weighs less than 10kg including 10 liter milk can.

- The machine consumes very low energy (60W) compared to a conventional milking machine (over 1000W) of similar capacity.
- Battery charging can be done by a 10W photo-voltaic cell or by a low power (1A) AC battery charger.
- Weight of the teat-cup assembly is 600g (conventional one weighs is over 2kg).

Udder health study and further improvements.

A commercial prototype of a solar powered portable milking machine developed (Model 3) for the small and medium scale dairy farmers in Sri Lanka was tested for the udder health. Based on the observations modifications were done to the teat cups by changing the engagement mechanism.

The developed solar powered portable milking machine was tested for milking cows at Mawelawatta Livestock Field Station, University of Peradeniya for udder health. A cow with average yield of 7 l/day was used for testing the milking machine. The average milking time for collecting 10 liters of milk was 7 minutes.

The conventional milking machine was design to work with 230 V and electric power requirement of the machine was 0.75 kW. Weight of the machine was 36.5 kg.

In this research full hand milking was practiced as a hand milking method. The correct and best milking method is with the full hand. The teat is held in the hand and the milk is expressed with the fingers, just as a calf takes the whole teat in its mouth and expresses the milk with its tongue. With this method no lubricating ointment is necessary.

External teat conditions were optically recorded just prior to udder preparation for milking, immediately following machine removal and three times in ten minutes interval after stopping the milking. A measuring tape scale was used to take the measurement. Teat length and external teat circumferences were measured in the same location in each and every teat. Teat circumference is measured in three locations. They are neck of the teat, middle of the teat and end of the teat. Instead of those parameters milk yield and milking time were recorded.

Those parameters had been taken during early morning milking for seven days. Conventional mobile milking machine and hand milking were also practiced like that way to compare the functional efficiency of a developed commercial prototype of a solar powered portable milking machine.

The milk yield variation with three milking methods cannot be compared as the milk yield decreases with time. Milking was done consecutively for 7 days for each method of milking and the yield was declining with time.

Teat length measurements were taken before and after milking for the tree milking methods tested and the data are listed in table 5. Generally, immediately after stopping of each and every milking method, teat elongation and contraction of teat circumference can be observed.

Table 5. Teat length variation before and after milking.

Teat number	Teat length (cm)					
	Conventional Milking machine		Hand milking		Newly developed portable milking machine (Model 3)	
	Before milking	After milking	Before milking	After milking	Before milking	After milking
1	6.971429	7.457143	6.714286	6.885714	6.114286	6.485714
2	5.857143	6.514286	5.928571	6.142857	5.928571	6.171429
3	6.714286	7.242857	6.728571	6.957143	5.942857	6.585714
4	5.771429	6.585714	5.6	6	5.528571	6.128571

Figure 21. shows the length variation of the 1st teat under three methods of milking. Figure 22 2through 24 shows the variation of circumference of the 1st teat.

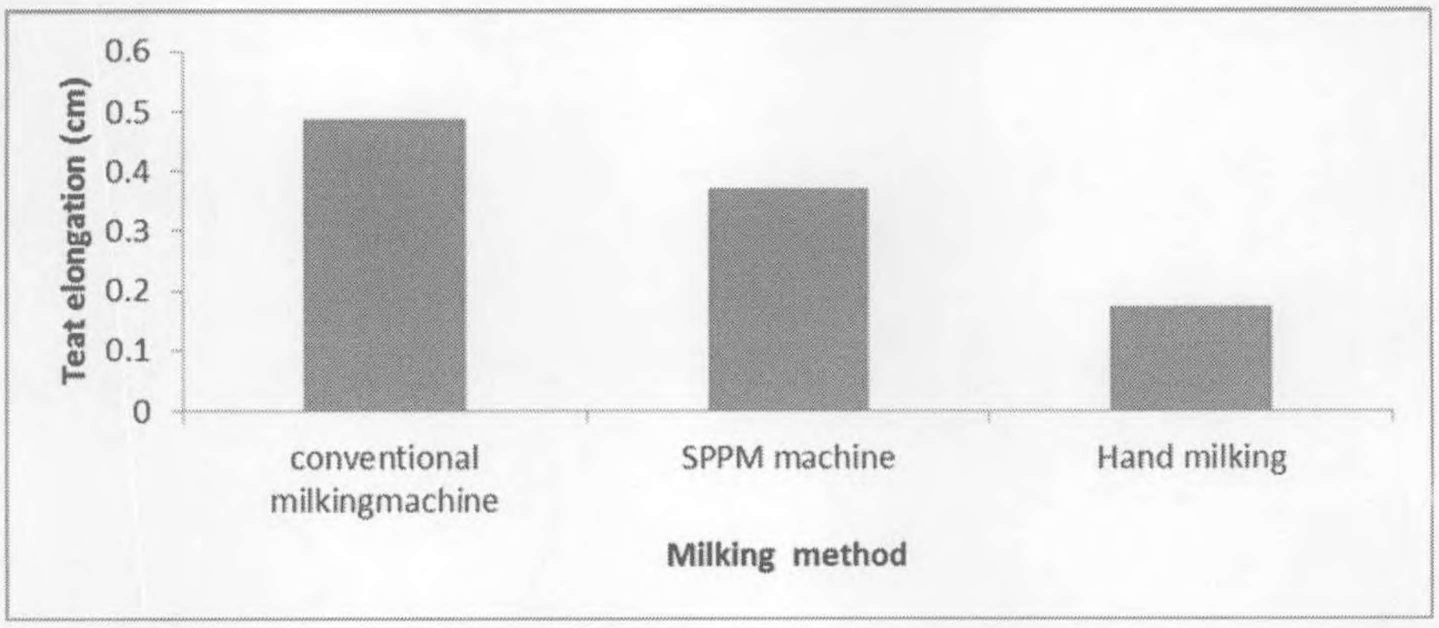


Figure 21. Average teat elongation with different milking methods (teat one)

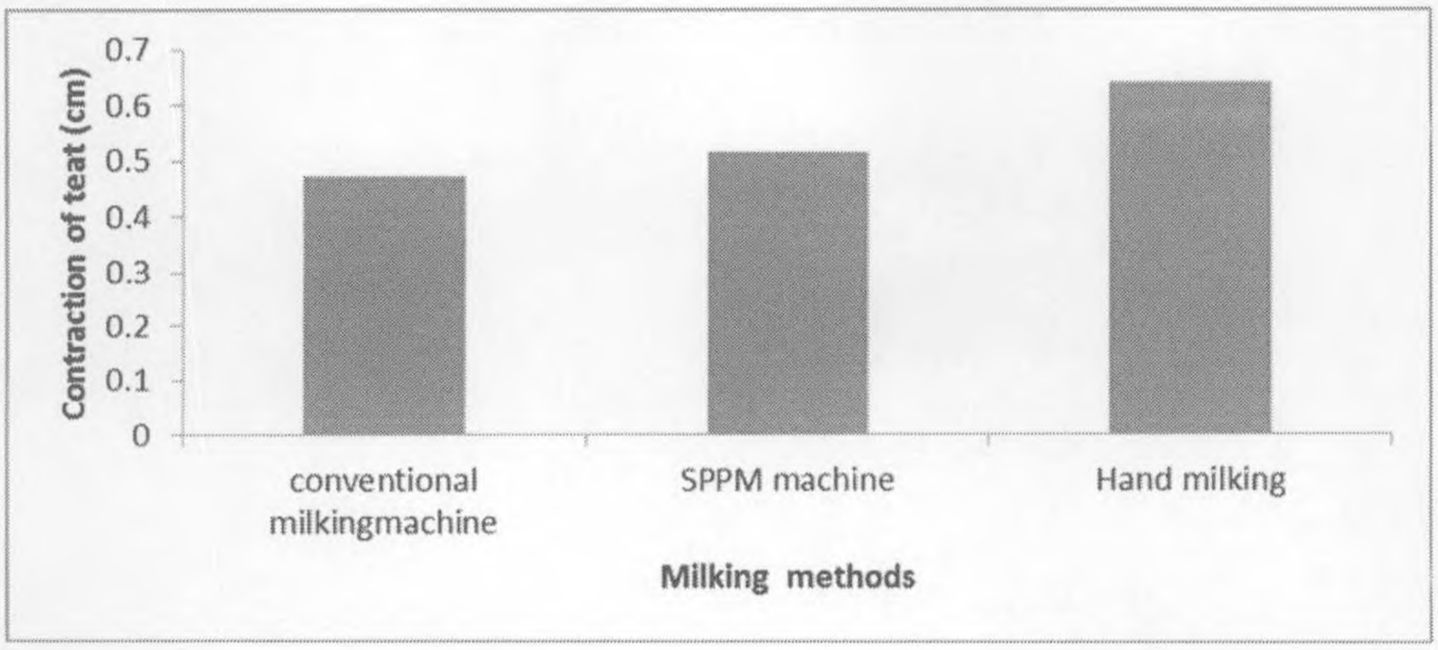


Figure 22. Average neck of teat contraction with different milking methods (teat one)

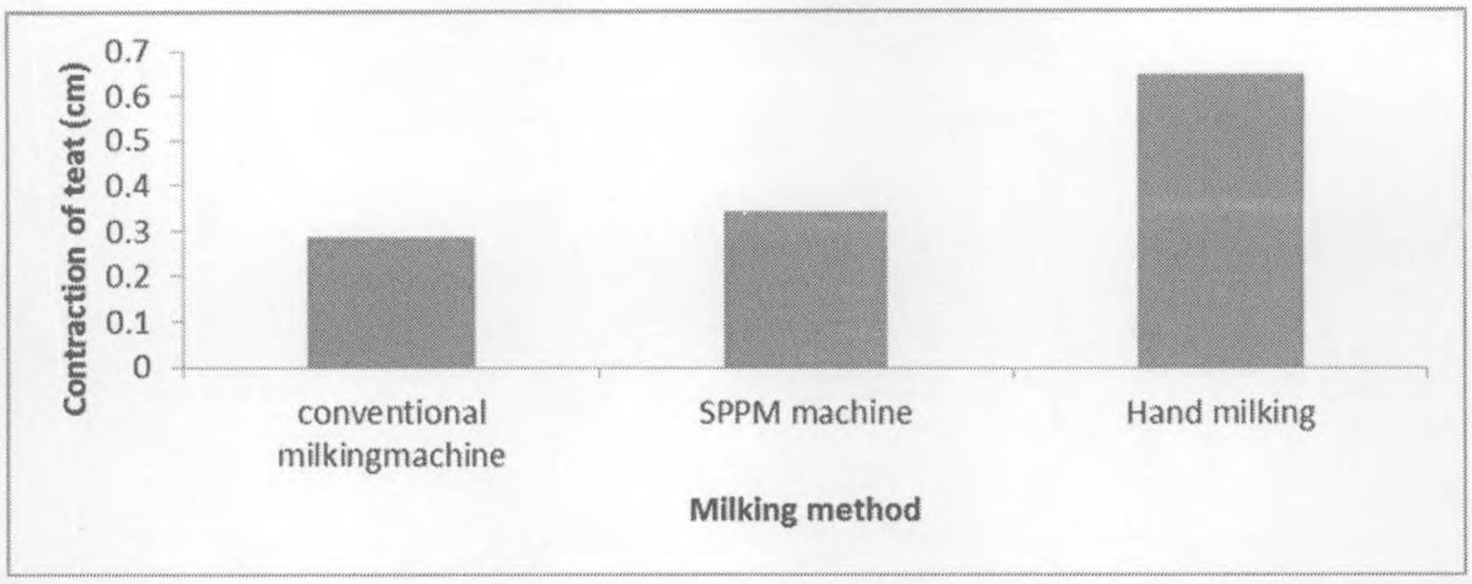


Figure 23. Average middle of teat contraction with different milking methods (teat one)

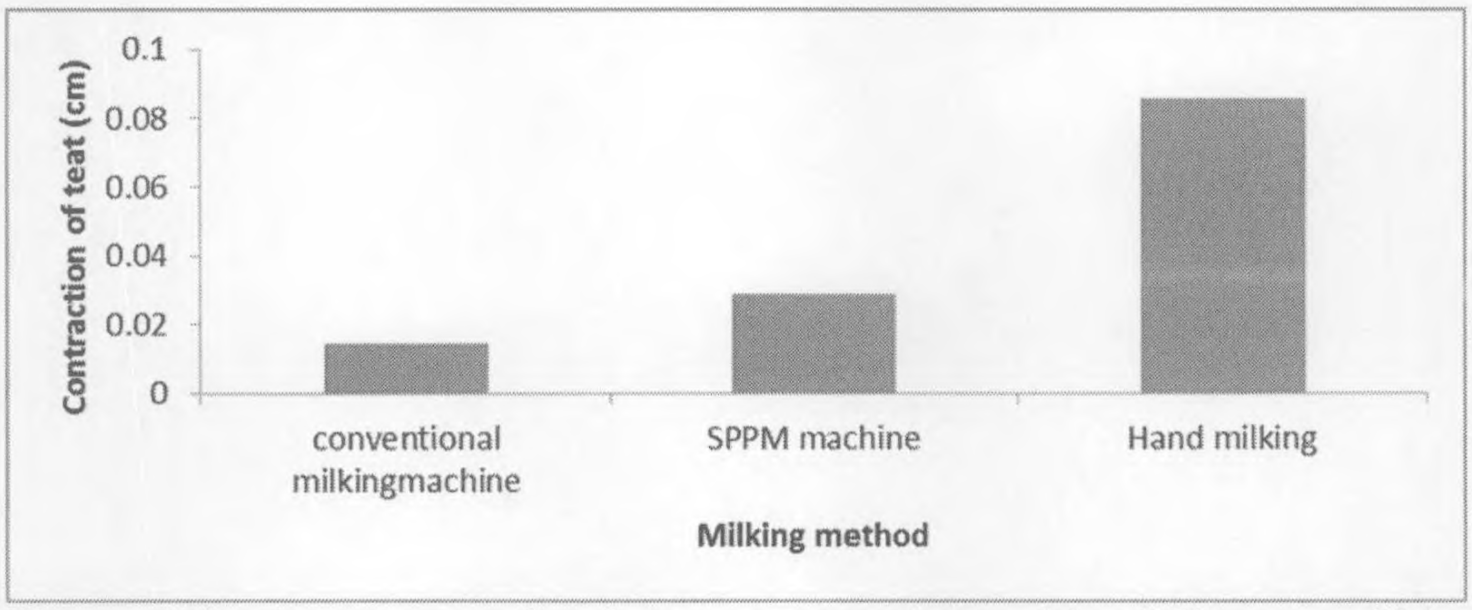


Figure 24. Average end of teat contraction with different milking methods (teat one)

Analysis of variance (single factor) was performed to see whether there is any difference among method of milking. According to the results, there is no variation among the method of milking in terms of teat length or teat circumference.

5.0 Discussion Results and Observations

- The newly developed solar powered portable milking machine performs similarly as conventional milking machine and hand milking. Therefore it can be concluded that newly developed solar powered portable milking machine can be used for commercial milking without having any adverse effects to the teats of cows.
- The newly developed solar powered portable milking machine is a low cost machine compared to the imported portable milking machines and suitable for small scale and medium scale farmers in Sri Lanka.
- The weight of the newly developed machine is comparatively low and easy to handle.

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