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Experimental Investigation of the Decaying Performance of Hydraulic Knee Controllers

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REHAB*Tech* is finance and supported by

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EXPERIMENTAL INVESTIGATION OF THE DECAYING PERFORMANCE OF HYDRAULIC KNEE CONTROLLERS

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ABSTRACT

Failures concerning hydraulic knee controllers have largely been ignored, and to this date no one has established a suitable and simple mechanism to allow for early detection of these failures. Failures in hydraulic knee units can result in oil leakage and loss of support, bringing about embarrassing and dangerous situations for the amputee. It was found, based on a small sample selection, that the time for the unit to return to its equilibrium position from full displacement, varied greatly between the new and old units, suggesting a simple stop watch could be one method of early detection of catastrophic failures. At cold temperatures, approximating conditions of high altitude Victorian winter conditions, failure occurred in the newly reconditioned unit. The result of this was significant, since it concluded that catastrophic failure occurs, despite one manufacturer's statements that imply these failures do not occur.

1.0 INTRODUCTION

Prosthetic knees provide three functions: (1) support during stance phase, (2) smooth and controlled swing phase, and (3) unrestricted flexion for sitting, kneeling, stopping and related activities.

Hydraulic knee controllers consist of a piston rod that is attached to the thigh section of the prosthesis behind the knee bolt. Knee flexion forces the piston down into the cylinder, which in turn forces fluid through a bypass channel at the bottom of the cylinder. The fluid travels upward within and around the sides of the cylinder, through a port at the top of the cylinder, and back into the central cylinder above the piston [1].

The hydraulic knee assists the extension process by the use of a spring. The spring is compressed during knee flexion allowing it to recoil and propel the shank into full extension, reducing the effort expanded by the amputee.

Hydraulic control uses liquid as its medium. Liquid provides resistance to motion depending on viscosity and temperature. Silicone oil is used in most prosthetic hydraulic units because it minimises viscosity changes with temperature, thus avoiding stiffness in cold weather and looseness in hot weather.

The hydraulic units can be reconditioned several times throughout a life time, with each recondition providing approximately two million cycles or two years of use. The units can last as long as 25 years with the appropriate maintenance.

MONASH REHABILITATION TECHNOLOGY RESEARCH UNIT (REHAB Tech) suggests that prosthetic hydraulic knee units exhibit catastrophic failure on a regular basis [1], while MAUCK LABORATORIES INC (MAUCK), a leading manufacture of hydraulic knee units, responded to the problem by saying that the units "should be returned for servicing not used until catastrophic failure occurs". MAUCK also stated "Unfortunately I'm not sure your initial idea of developing a simple device to test the performance decay is feasible". CATECH, another manufacturer of hydraulic knee units, declined to respond to the problem [2][3][4].

The units that were to be tested were CATECH units. Both units have been reconditioned approximately seven times each. The 'new' unit has recently been reconditioned, while the 'old' unit came from a patient complaining of poor performance.

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2.0 METHODS OF CHARACTERISTIC DETERMINATION

The hydraulic unit obtains its resistive action by the use of a viscous fluid. The viscosity of a fluid is a function of the temperature of the fluid, and is related to the shear stress and shear rate being applied.
The extension assist is obtained in simple form by the use of a spring. The spring's behaviour is essentially characterised by either its displacement or the force being applied to it ($F = kx$).

The above characteristics were taken into account in setting up the experiments to assess the decaying characteristic performance of the hydraulic knee.

If the catastrophic failure was to occur in such a form that the unit failed to provide its resistive behaviour , it would indicate the fluid was not obtaining the required shear resistance, or a valve or port had failed. One method to ascertain the condition would be to measure the time taken for the unit to release itself from the compressed position. Since the viscous shearing resistance (viscous effect) is proportional to the square of velocity, it is inversely proportional to the square of time for a given displacement.

It is important to note that if the spring were to fail it would also be indicated in the above test, as it would take longer for the unit to return to its equilibrium position, if it returned at all.

Since the viscous effect is also dependent on temperature , a test can be performed simulating the walking motion at various temperatures, measuring the force required to obtain that motion. In other words it will measure the force to overcome the viscous effects. As the viscosity changes we could expect the force required to provide motion to change also. By doing this at various temperatures we may be able to highlight a weakness in the unit with the temperature change acting as an amplifier.

3.0 METHODOLOGY

For the time-relaxation test the unit was clamped, and a displacement transducer attached to it. The transducer sent a voltage to the computer via an analogue-to-digital converter (ADC) where it captured the data in a data acquisition program called DTV. A program was written in DTV to allow for the appropriate sampling to be obtained. The DTV program allowed us to input the known displacement of the unit, and then converted the displacement data into real time data. The hydraulic knee unit was displaced fully and released simultaneously with the push of a button which started the program. This was repeated for various settings of extension and flexion adjustments on both the new and old units. The data was analysed in EXCEL. Refer to Figure 1 for experimental layout.

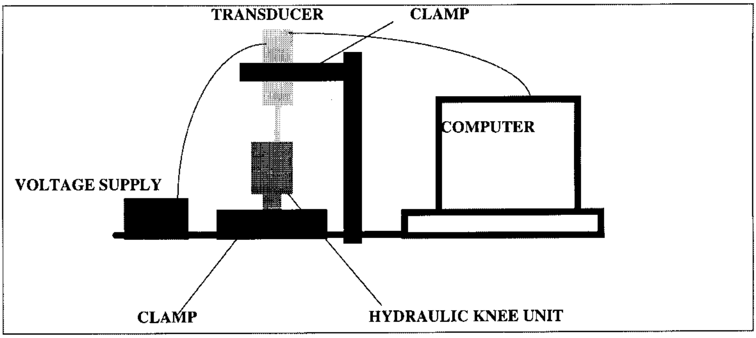


Figure 1 - Layout of Time-Relaxation Test

With the temperature test, the Instron machine was set up to perform a typical walking cycle and both the new and old units were cooled to approximately 1°C and tested and then heated to 40°C and tested. The data was monitored on computer and simultaneously stored in an EXCEL file. The data stored contained the FORCE required to obtain walking motion and corresponding TIME values. This was performed at various settings on the knee units. The two temperatures were chosen since they approximated the extreme living conditions of Victorian weather.

One other test was then done using the Instron machine at temperatures of approximately 20°C. This test was to be performed as an endurance test at a medium setting for both flexion and extension on the units in a similar manner as above. The idea was to take samples during the test and compare its changing characteristics.

4.0 RESULTS

4.1 Time -Relaxation Test

The results of the time relaxation test are shown in APPENDIX A. It is important to note that the value of the series corresponds to the unit being tested. Series 1 is the new unit while series 2 is the old unit. From these graphs we can see that the new unit takes a much longer time to reach its full extension than the old unit does. This implies the new unit is providing a much greater degree of resistance than the old unit. This appears to be much more pronounced when the flexion is set to a maximum.

4.2 Instron Temperature Test

The results are outlined in APPENDIX B. Once again series 1 corresponds to the new unit and series 2 the old unit. From these results we can see a clear distinguishing difference between the force required to provide the desired walking motion, particularly in the initial flexion of the units. However before we make conclusions on these tests it must be stated that on the first run of the cold test with the new unit, a loud snap was heard during initial flexion.

The hot test was then performed and it was noticed that the new unit was leaking excessive oil everywhere. This probably occurred during the cold test when the loud snap was heard. This implied that catastrophic failure of the new unit had occurred.

Due to the failure of the new unit and the excessive leaking of oil, it became impractical to continue with the hot test, so no comparisons were made.

4.3 Endurance Test

The last test to be performed was an endurance test. Since the new unit was broken it was decided not to perform a comparison, but rather to gather data on the old unit to see how the characteristics change.

The test results are outlined in APPENDIX C. Initially the test was planned to run for two hours, however excessive heating of the unit occurred. Within ten minutes the unit was operating at temperatures above 70°C. After 25 minutes the test was stopped since the outside casing of the unit was well above 90°C. The large temperature change was unexpected, and the characteristics did not change significantly. There was a shifting in the force requiring less force to extend the knee and more force to put the knee in flexion. This however could be explained by an expansion of the spring due to temperature, and a larger force required to fully displace it, resulting in a lesser force to return it to its equilibrium position.

5.0 RECOMMENDATIONS

From the test results it appears as if the time-relaxation tests provide a key to solving the problem. It is important to stress however, that the data was collected from the testing of only two units and can not be considered conclusive.

It is suggested that a more advanced set-up of the time-relaxation test be made, ie with automatic release mechanisms for the unit, making it more accurate. As part of this testing it would be a further recommendation to test at the very least five units of both new and old condition.

It would also be wise to test several units from new condition until they deteriorated. This would help in establishing if there is any particular point at which servicing should be obtained, and in particular if there is any point that suggests failure is about to occur.

It is also important to stress the fact that by no means will the time-relaxation test determine every failure, however it implies that an indication may be obtained from it.

A final and further recommendation of the report would be to design and place a built-in monitoring system into the unit which would be able give warnings if the unit was not operating as desired. This could be achieved by setting up small transducers in the knee with a microchip capable of comparing the data received from the transducers to that stored in the memory as recommended values.

6.0 CONCLUSIONS

The time-relaxation test indicates the best method for determining in a simple form how deteriorated the performance of the hydraulic unit has become. If this test was to become clinical, it would require a stopwatch or simple data acquisition program to obtain the data, and then a comparison of this data to recommended values provided. If the values were close to critical the user could then receive the appropriate servicing, if not the approximate life could be determined. If the test was as simple as a stopwatch, then the user would not require to go any where for testing, instead the user could simply test the unit and check the results in a manual of their own.

7.0 ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of Mr. Bill Contoyannis of Monash Rehabilitation Technology Research Unit in regard to providing artificial knee controller units for testing and valuable technical advice, and Mr Vincent Rouillard of Victoria University of Technology for his technical assistance during testing.

8.0 REFERENCES

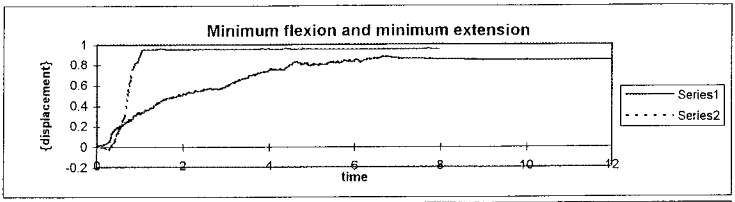
1. Rubin, R.M.D, Clinical Prosthetics and Orthotics, Volume 7, Academy of Orthotists and Prosthetists, 1983.

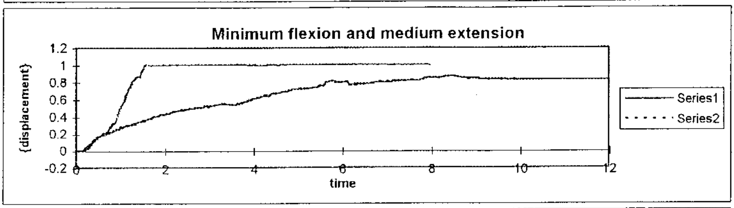
2. Personal communication with Bill Contoyannis at Monash Rehabilitation Technology Unit.

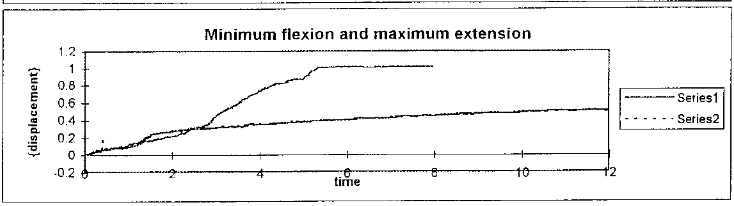
3. Personal communication with W. Phillips, President and CEO, MAUCK, USA, April 1995.

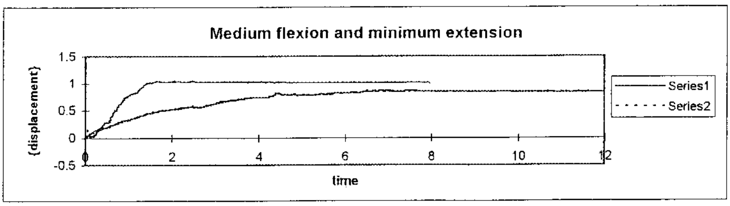
4. Personal communication with L. Wiggins, President, CATECH, USA, April 1995.

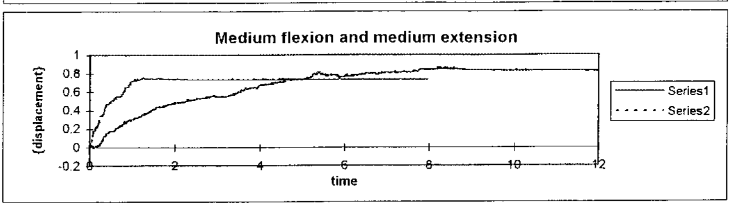
APPENDIX A


Minimum flexion and minimum extension
{displacement}
time
Series1
Series2

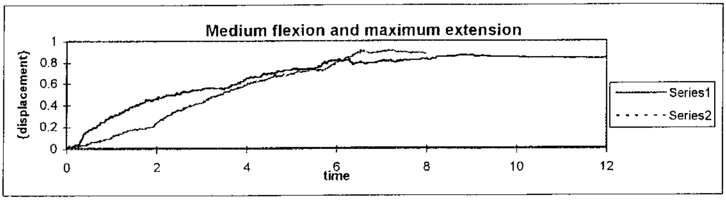

Minimum flexion and medium extension
{displacement}
time
Series1
Series2

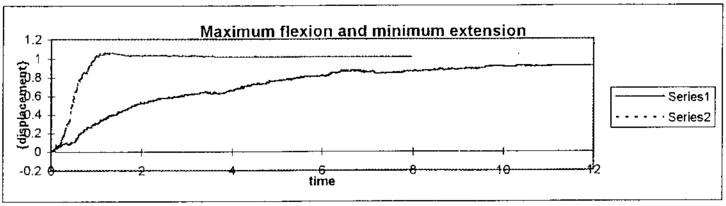

Minimum flexion and maximum extension
{displacement}
time
Series1
Series2

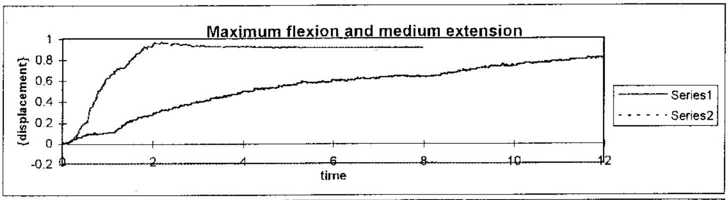

Medium flexion and minimum extension
{displacement}
time
Series1
Series2

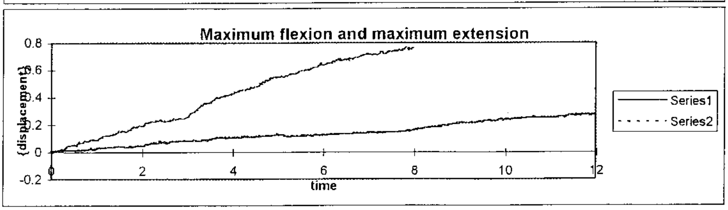

Medium flexion and medium extension
{displacement}
time
Series1
Series2

APPENDIX A
(continued)

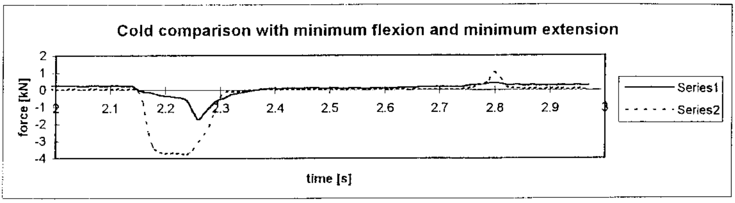


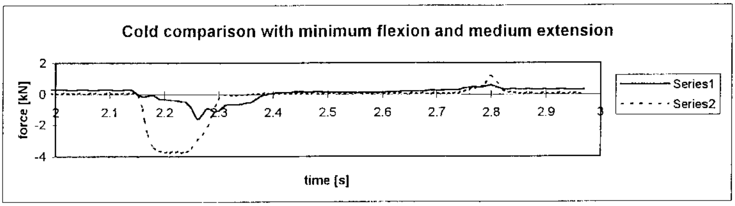


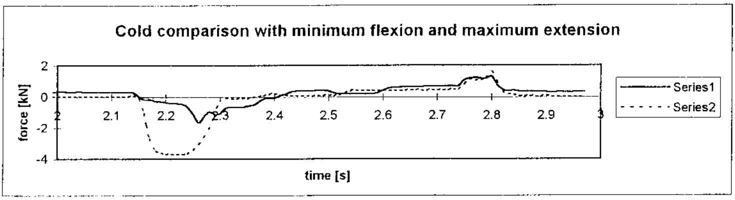


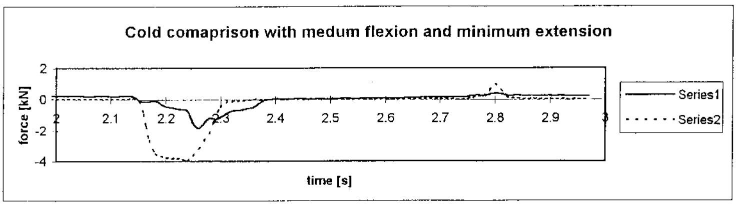


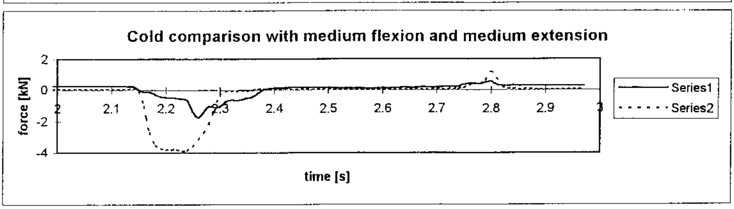
APPENDIX B

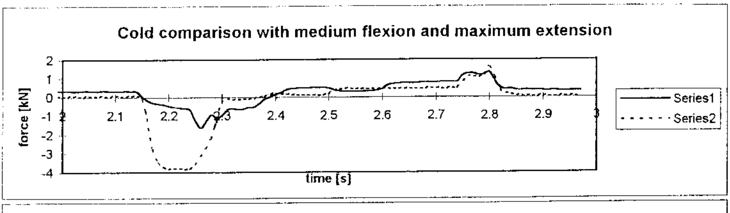

Cold comparison with minimum flexion and minimum extension
force [kN]
time [s]
Series1
Series2

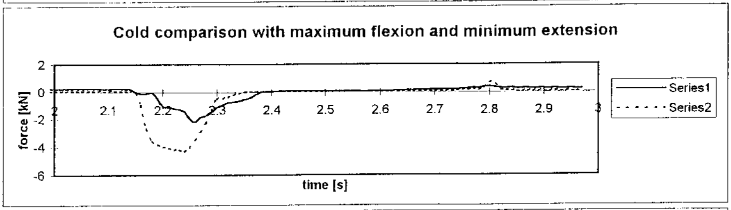

Cold comparison with minimum flexion and medium extension
force [kN]
time [s]
Series1
Series2

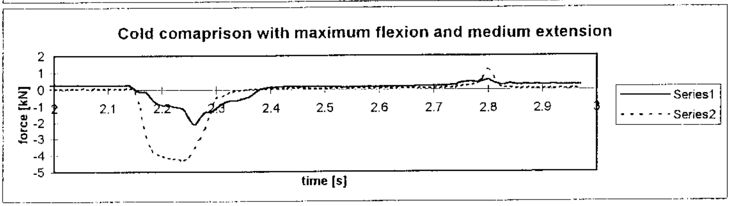

Cold comparison with minimum flexion and maximum extension
force [kN]
time [s]
Series1
Series2

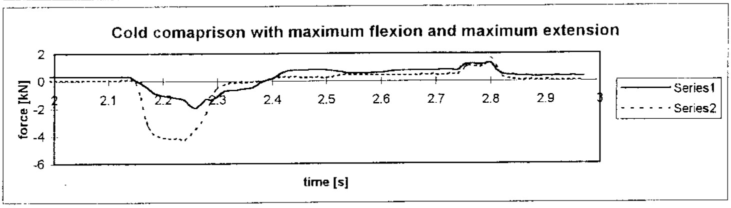

Cold comaprison with medum flexion and minimum extension
force [kN]
time [s]
Series1
Series2

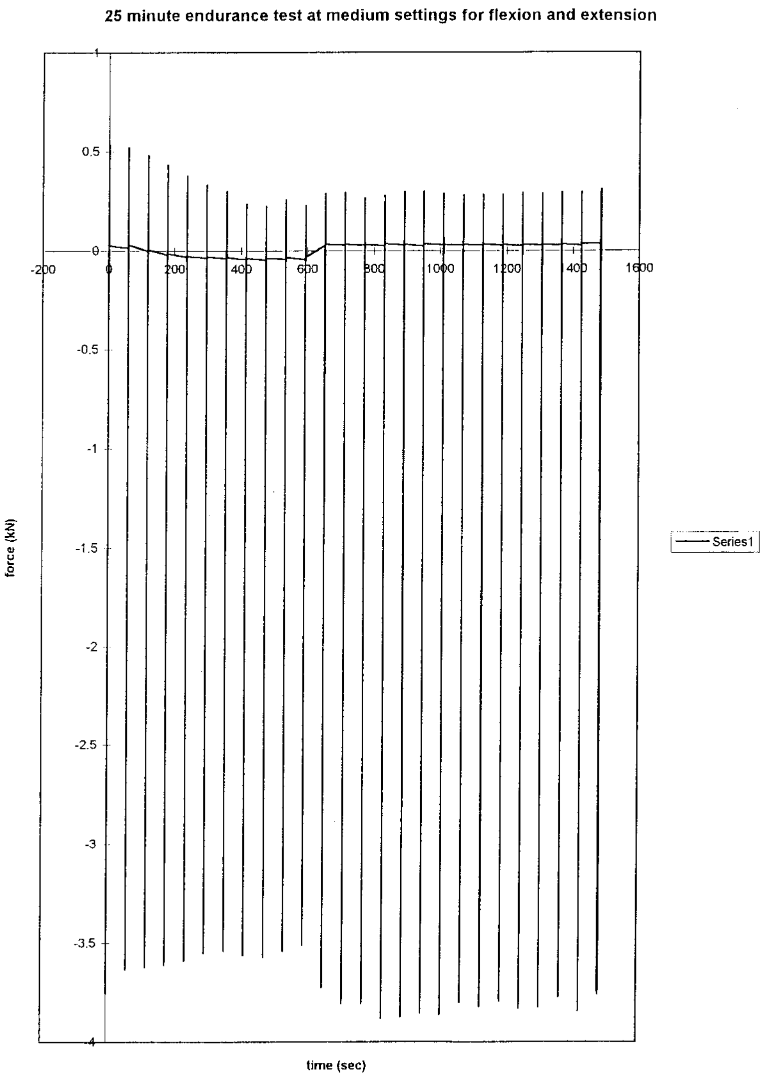

Cold comparison with medium flexion and medium extension
force [kN]
time [s]
Series1
Series2


Cold comparison with medium flexion and maximum extension
force [kN]
2
1
0
-1
-2
-3
-4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
time [s]
Series1
Series2


Cold comparison with maximum flexion and minimum extension
force [kN]
2
0
-2
-4
-6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
time [s]
Series1
Series2


Cold comaprison with maximum flexion and medium extension
force [kN]
2
1
0
-1
-2
-3
-4
-5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
time [s]
Series1
Series2


Cold comaprison with maximum flexion and maximum extension
force [kN]
2
0
-2
-4
-6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
time [s]
Series1
Series2


25 minute endurance test at medium settings for flexion and extension
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-200
0
200
400
600
800
1000
1200
1400
1600
force (kN)
time (sec)
Series1