OFFSET FEED PARABOLOIDAL AND SHAPED REFLECTORS FOR SOLAR ENERGY CONCENTRATION

By

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CERTIFICATE

i) I am satisfied that the thesis presented by S. NATARAJA MURTH is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bonafide research work carried out by him under my guidance and supervision and that the results contained in is have not been submitted in part of full to any other university or Institute for award of any degree/diploma.

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ABSTRACT

The present thesis deals with the application of the offset feed paraboloidal and shaped reflectors for solar energy concentration. The offset feed paraboloidal reflectors which are used in space communications are found to be extremely suitable for solar energy utilisation because of the flexibility they offer in locating the absorber and for elimination of the blockage of the aperture by the absorber. These reflectors are suitably applied for solar energy concentration on an absorber kept inside the window of a south or near-south facing wall or a south facing corner and the thesis deals with the design of the wall mounted hour angle-declination mount designed by the author for achieving this objective.

The convective heat losses are minimised at the absorber as it is kept inside and the effect of the wind velocities or turbulence is reduced. The radiative heat losses are reduced by providing spatial emissivity control. A built-in partial radiative heat shield is also provided by carving the geometry of the reflector. These two improvements are carried out without going for extra casings which reduce optical efficiency and also add to the cost of the device.

As the Offset Feed Paraboloidal Reflector (OFPR) is asymmetric, the energy distribution at the focus has been studied and the results are presented. The shapes of the reflector which provide uniform illumination on a Conical Sectorial Absorber and on a sector of a spherical absorber have been worked out and presented. The radius of the absorber is optimised for minimising

the overall losses. Utility of the reflector for multiple purposes like water heating, cooking and photovoltaic power generation has been described.

All the parameters of the offset feed paraboloidal reflector like the clearance, focal length, outer radius, the limitations on the height of the roof for indoor operation and the sectorial angle have been worked out for every 2° latitude range between 8° to 32° latitudes, against the towns and areas in India falling in the respective latitude ranges.

Various phases in the development of the device have been reported with photographs and the computer programs developed for the analysis and presentation of the results and the copies of the technical papers presented / published are given in the appendix.

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I feel that this effort is rewarded when I find this reflector being used in rural and urban environs.

PREFACE

Paraboloidal reflectors (PR) have long been used for producing high temperatures for domestic and industrial use. A good amount of work has been reported on Solar Furnaces in India and abroad. But the paraboloidal reflectors have not been popularly used in many tropical countries though a large amount of sun shine is available with a good proportion of clear days in a year and the reflector could be made with cheaper and local materials. The reasons seem to be two fold, i.e. operational inconvenience and efficiency degradation due to exposure to outside weather conditions.

Operational inconvenience is caused by the exposure of the operator to the sun as in the tropics the sun is hot and there is scorching heat in the open weather. Also the absorber would have to be placed at an inconvenient location to handle. In small f/D systems as in the case of the sun-basket, the absorber is deep in the reflector and it is to be taken out with a rope or inserted. For large f/D systems the focus is at an inaccessible height. For the powers of the order of 1 Kw for domestic applications, the height of the focus from the vertex is around 1.4 m to 2 m for f/D of 1 to 1.4 keeping the absorber almost inaccessible. The absorber's orientation, when it is kept at the focus, changes and it requires frequent adjustment to keep it vertical.

This inconvenience takes another shape in industrial applications. The heat engine kept at the focus will also have to be carried by the mount increasing the load on the tracking system.

From the efficiency point of view, the paraboloidal reflector provides a high power to area ratio but has many draw backs, one of them being the aperture blockage by the absorber for domestic applications and heat engines etc for industrial applications. The other factors leading to loss in efficiency are (i) exposure of the absorber to the weather conditions in the open leading to high convective losses and (ii) the minimal flexibility offerred for reducing the radiative heat losses except by the reduction of the size of the absorber. Any casings used to reduce convective and radiative heat losses reduce optical efficiency. They are costly and easily breakable.

Offset feed paraboloidal reflectors (OFPR) which are used in space communications are found to be extremely suitable by the researcher for solar energy utilisation because of the flexibility they offer in locating the absorber and for the elimination of the blockage of the aperture by the absorber. In addition to applying them for solar energy concentration on an absorber kept indoor, the convective and radiative heat losses are minimised with no external casings over the absorber and the overall efficiency is improved. The energy distribution at the focus of the OFPR is studied and shapes of the reflectors have been arrived at for obtaining uniform illumintion on a Conical Sectional Absorber (CSA) and on the sector of Spherical Absorber (SA). The radius of the absorber is optimised for minimising the overall losses and other parameters of the OFPR like the focal length, sectorial angle, inner radius, outer radius and clearance are worked out for indoor operation at different latitudes. Finally the mechanical fabricational details for making the reflectors in small numbers are given. The thesis reports the work done by the researcher on these aspects.

A Chapter Wise Summary Of The Thesis:

A review of the research and developmental work carried out on various types of concentrators has been presented in Chapter 1. The problems experienced in using solar concentrators for domestic and industrial purposes are enumerated. Recent advances made in the reflector design for achieving desirable objectives in the space communications have been highlighted and how those configurations can be used for solar energy purposes for increased operational convenience has been described. A brief account of the work carried out by the author is also given.

Chapter 2 deals with the basic geometry of the OFPR with sectorial and circular apertures and identifies their location in the family tree of PR. The hour angle declination mount developed for countering the diurnal motion of the earth is explained which facilitates a simple movement in one axis in a day and easy orientation to the sun by a single pointing rod. Various stages in perfecting the design from conceptual stage upto the realisation are explained i.e., tin sheetmodel, glass mirror reflector model, rural full scale model, urban full scale model and the urban 1/5th model. Possible variations of the device are outlined. The criteria for unobstructed movement of the OFPR in winter and nonshading by the roof in summer for indoor operation are defined. The selection of sectorial angle which facilitates fixing up the OFPR in south facing or near-south facing walls is outlined.

The improvements affected to increase the optical efficiency are given in Chapter 3. The elimination of the aperture blockage by the absorber has been quantified, which amounted to losses of the order of 5 to 8% of the input power. The elimination of the aperture blockage removed the restriction on the size of the absorber but the radiative heat losses still prevented a large size. Hence a study has been made as to what extent the absorber size can be increased in the OFPR so that the radiative heat losses can remain the same as that kept in PR by going for the Spatial Emissivity Control principles adapted in space craft thermal design. The blackenning of the absorber is so done as to accept the solar rays from the reflector and the spill over losses are reduced by going in for larger absorber size. The conditions under which this is possible (viz. the optical angular extent of the larger absorber being larger than that of the small absorber) is explained in this chapter. The reduction of the spillover losses in a typical case is to an extent of about 3% (i.e. 21% to 18%). In arriving at the intercept factor for PR, the r.m.s. optical error slope is taken to be a vectorial sum of the r.m.s errors of the radial and circumferential slope errors. Since the OFPR is an asymmetric reflector the average spillover obtained by multiplying individual components is expected to be different from that obtained through the vector sum. Surprisingly there is no serious disagreement between these two methods. The spill over reduction calculated either way in the case of OFPR is almost the same in a typical case.

The thermal efficiency improvement was affected by reducing the convective heat losses and restricting the radiative heat losses and the methods adopted are described in Chapter 4. Convective losses are reduced by keeping the absorber inside a room, the south facing or near-south facing exterior of which carries the reflector. The savings in convective losses are sizeable. In a typical case they can be reduced from 18% of a PR to 9% in OFPR without going for extra glass covers. The radiative losses though cannot be reduced in OFPR, can be atleast made the same as in PR by employing spatial emissivity control. Another method suggested and brought out in OFPR shape is that a partial radiative heat shield is built-in, which maximises the ARHC factor (Auto Radiative Heat Conservance). For example if the heat radiated at the normal to the absorber surface impinges on the reflector such that a portion of absorber intercepts the reflected radiation, radiative loss is conserved. The geometry can be carved in such a way as to obtain 12.5% conservancy in radiative heat loss, accounting to an overall efficiency increase to the order of 2 to 6% for temperature ranges of 500 K to 600 K in a typical case.

The offset feed paraboloidal reflector (OFPR) under consideration is an assymmetrical reflector, as against an axi symmetrical paraboloidal reflector (PR). The energy distribution of this reflector would be very much different from that of the PR especially when the reflector is misaligned in both the axes. Hence the energy distribution on a flat sectorial plate held perpendicular to the focal line is studied for non tracking of OFPR for significant time intervals in both the axes. The behaviour of the reflector is presented in Chapter 5. The reflector has high tolerance for non-tracking of the reflector in declination for a few days and in hour angle for a few minutes. Computer plots made for different error combinations show some typical angle misalignment at which some specific advantages can be derived. The traditional ray tracing principles are invoked for arriving at the results.

The energy distribution at the focus of the OFPR is highly non-uniform and for thermal applications this fact is of little concern. But for absorbers like the photovoltaic assemblies working on concentrated illumination the energy distribution should be uniform or of a specific pattern. This can be achieved by shaping of the reflectors which is discussed in Chapter 6. Synthesizing the shape of axisymmetric reflectors for uniform illuminations for low concentrations on flat and spherical absorbers has been already done earlier by Burkhard and Shealy. Since a conical sectorial absorber (CSA) would provide maximum ARHC in one orientation for use as water heater and minimum ARHC for use as photovoltaic assembly, the shape of the reflector for such an absorber is synthesised on similar lines and the same is extended to a sector of a spherical absorber also. It is found that a shaped reflector (OFSR) which provides uniform illumination on a CSA is less curved than PR surface and an OFSR providing uniform illumination on a SA is more curved than PR surface. The co-ordinates of the generating curves for OFSR and CSA and OFSR and SA combinations are given, for concentrations of the order of 37 and 18.5 suns respectively which are chosen on the basis of economical considerations.

The selection of OFPR parameters like the sectorial angle, focal length, inner and outer radii and clearance for unobstructed movement in winter for northern latitudes has been discussed in Chapter 7. From the efficiency point of view the optimal radius of the absorber to keep the total losses minimised is found and tabulated against the surface finish inaccuracies. The results of the studies regarding selection of parameters and optimisation of the absorber size are interesting. For low latitudes a large focal length is necessitated and to reduce the outer radius of the reflector it is necessary to have a large sectorial angle. For high latitudes the focal length can be small and sectorial angle should also be small for facilitating indoor operation. For a 1 KW range solar stove the absorber size ranges from 7 cm radius to 19.8 cm radius, for slope errors of 1 in 40 to 1 in 12 leading to overall efficiencies of the order of 83% to 70% for temperatures of 277° C. A study of the extra blacken ing required to accommodate the larger width of the half solar angle is also included in this chapter for obtaining some energy in cloudy days.

Chapter 8 provides the mechanical fabricational details needed to fabricate 1 KW range OFPR in small quantities for the rural and urban models and their performance. It is ancitipated that the device will also be popular for providing medium powers of the order of 400 and 500 W where a 150° sectorialangle OFPR with just 0.75 m outer radius made of plastic sheet finds application in hospitals, laboratories and houses. A 40 W demonstration model with hardly 24 cm outer radius is accepted with interest by ordinary public during demonstration. The performance of solar device can be estimated by the stagnation temperature achieved at high temperatures and by calorimetric methods at low temperatures. While the stagnation temperatures were of the order of 277° C to 300° C, the efficiencies derived from calorimetric method were about 80% (including thermal losses) which agree with the theoretically estimated values. The area moments about different axes are also given for the OFPR sectorial and circular aperture systems, which are useful in balancing of the reflector.

In Chapter 9 the work which can be carried out further for indoor utilisation of solar energy has been outlined. The developmental work which can be carried out on the reflectors and mounts has also been outlined for cost effective usage.

The appendices include the computer programs developed for plotting the energy distribution, the length of the generating curve, surface area, centroid, f/d and projected areas.

The work mentioned herein has partially appeared in the following publications given in appendix and the devices have been exhibited at the respective locations.

A.1. S. Nataraja Murthy "offset feed paraboloidal solar stove for indoor cooking applications" P.P. 3.030, National Solar Energy Convention, 1981.

A.2. S. Nataraja Murthy and N. Narasaiah "Energy distribution at the focus of offset feed paraboloidal solar stove" Vol 34, No.3, Solar Energy PP 279-285, 1985.

A.3. S. Nataraja Murthy "Offset Feed Paraboloidal Solar Stove". Invention Intelligence, 1982, Vol 17, No.1-2, Jan-Feb 1982.

A.4. S. Nataraja Murthy & S. Narasaiah, "Ensuring quality of electronic components exposed to cyclonic weather conditions" proceedings of 4th National Convention of Indian Association for Quality and Reliability, Trivandrum, Dec. 1983.

Demonstration

1. Demonstration at National Solar Energy Convention - 81 held in January 1982 at I.I.Sc., Bangalore.

2. Demonstration at ISTRAC/ISRO in May 1986.

3. Demonstration at 4th National convention for Quality and Reliability, Trivandrum, Dec. 1983.

CONTENTS

CHAPTER 6. Offset Feed Shaped Reflector (OFSR)

6.1 Introduction

6.2 Methods Adopted for Shaping

6.2.1 By deforming the Parabolic generatrix

6.2.2 By forming the generatrix as a polynomial

6.2.3 By geometrical optics synthesis

6.2.3 By synthesizing generating curve from energy balance equations

6.3 Concentration Ratio Considerations

6.3.1 Temperature effects for PV cells

6.3.2 Human safety considerations

6.3.3 Cost aspects

6.3.4 Selected value for concentration

6.4 Line Of attack for shaping

6.4.1 Shaping of offset feed sectorial reflector for uniform illimination on Conical Sectorial Absorber (CSA)

6.4.2 Shaping of offset feed sectorial reflector for uniform illumination on the sector of a Spherical Absorber (SA)

6.5 Examples of calculations for shaped reflector

6.5.1 Coordinates of a shaped reflector for uniform illumination on CSA

6.5.2 Coordinates of a shaped reflector for uniform illumination on the sector of a SA

6.6 ARHC of a shaped reflector for a uniform illumination PV attachment

6.7 Orientation of the absorber depending on its function