1. INTRODUCTION

The general principles involved in the design of a new analogue computer (Līlāvatī) for solving linear simultaneous equations were discussed in a previous paper (G. N. Ramachandran and E. V. Krishnamurthy 1958—referred to as Part I). It was shown there how, unlike other computers where loading effects introduce errors due to current drain and non-linearity, this computer could provide an exact analogy of the set of equations to be solved, by making use of Ohm’s law for multiplication and null methods for comparison of voltages. Even though these were the methods used in Model I for setting up the analogy, the measurements of voltages and currents were only done by meters, which are in principle not capable of highest precision. If exact measurements are to be made, only potentiometric methods should be used and meters should be completely dispensed with. Quite apart from the question of accuracy, the potentiometric arrangement has also other advantages;

(a) Considerable economy is possible in material and in number of operations;

(b) The circuit can easily be modified to solve secular equations;

(c) Operations can be made both with a.c. and d.c. without changing the circuit appreciably.

This paper primarily deals with the design of Model II of Līlāvatī, employing potentiometers and its applications. Still further improvements are possible if one makes use of different iterative methods for solving both
simultaneous and secular equations and if corresponding changes in circuitry are made. A discussion of these is reserved for Part III.

2. THE POTENIOMETRIC ARRANGEMENT

The essential idea, as was mentioned in Part I, is to measure both currents and voltages by means of a standard potentiometer, the latter directly and the former by incorporating a standard resistance in the current circuit and measuring the voltage developed across it. In building Model II, the main aim was to test the suitability of potentiometric circuits in the design of the computer and consequently all components were designed only to have an accuracy of two significant figures (or 1%).

The potentiometric arrangement itself is shown in Fig. 1(a) and it could be used for measuring any voltage between 0 and 1·1 Volts to an accuracy of 0·01 V. It consists of a two-decade resistance box (R), the current through which could be varied by means of a variable resistance R1. In order to standardise it, a standard Weston cell is connected across 101 Ω, with a tap key K and a galvanometer G. If the key K is pressed and the rheostat R1 is adjusted for no current in G, then the potentiometer is standardised.
By means of two 11-way switches A and B, whose 11 ways are connected respectively to the points $a_0$ to $a_{10}$ and $b_0$ to $b_{10}$ of the two-decade resistance box, any voltage value between 0 and 1·1 V. can be obtained across A and B, according to the setting of the switches A and B.

In order to measure the current, a standard resistance of 100 $\Omega$ ($r$) is included in the current circuit and the potential drop across it is compared with that between the points A and B of the potentiometer as shown in Fig. 1 (b). The switches A and B are adjusted for balance and their setting gives straightaway the currents in units of 0·1 m Amp. The same method can be used to measure any voltage in the range 0 to 1·1 V. in units of 0·01 V. [Fig. 1 (c)].

3. THE NEW CIRCUIT

In order to solve a set of equations:

\[ a_{11}x_1 + \cdots + a_{1n}x_n = b_1 \tag{1} \]
\[ a_{21}x_1 + \cdots + a_{2n}x_n = b_2 \]
\[ \vdots \]
\[ a_{n1}x_1 + \cdots + a_{nn}x_n = b_n \]

the circuit shown in Fig. 2 is used.

Here the values of $a_{rs}$ are all fed in as resistances on 100 $\Omega$ wire wound volume controls by using an auxiliary Post-Office box arrangement, exactly as in Model I [see §4 (ii), Part I*]. On the other hand, the voltages $b_r$ are made equal to the required value by tapping the appropriate voltage from the potentiometer by switches similar to A and B. This is done by having a set of switches $A_1$, $B_1$; $A_2$, $B_2$; $\ldots$ $A_n$, $B_n$ similar to the set A, B for obtaining each of the values $b_1$, $b_2$ $\ldots$ $b_n$ respectively. This is possible for, in the Gauss-Seidel iterative process only one equation is set up at a time.

The arrangement is shown in Fig. 3. The various potential points $a_0$ to $a_{10}$ and $b_0$ to $b_{10}$ in the two-decade resistance box of the potentiometer are brought to separate 1 pole 11 way switches $A$, $A_1$ $\cdots$ $A_n$ and

* Experience showed that use of coarse and fine adjustments, as in Model I, was unnecessary if only an accuracy of 1% was aimed at. Hence each coefficient was represented in a single 100 $\Omega$ volume control. The P-potentiometers which vary the current $x_n$ were also 100 $\Omega$ volume controls.
B, B₁ . . . Bₙ as shown in the figure. Thus the voltages b₁ to bₙ can assume any value between --1.10 V. to +1.10 V. in steps of 0.01 V. depending on the setting of the corresponding switches, which can be readily read off on dials.

FIG. 2. Analogy of a set of n-linear simultaneous equations.

FIG. 3. The setting switches.

The cross-connections needed for setting up one equation at a time are shown in Fig. 2. The connections there are shown as having been made.
for the first row. By means of a selector, as described in Part I [§4, (iv)], such connections can be made successively corresponding to each row of the equation from 1 to \( n \). The currents \( x_1 \) to \( x_n \) are adjusted, as before, for balance at each step. The value of the currents need not be read at intermediate stages, but they can be accurately measured by means of the switches A and B, when the iterative process has converged.

Thus in Model II, a single potentiometer can not only be used to obtain the voltage settings corresponding to the values \( b_r \) on the right hand side, but also for measuring the currents \( x_s \). Further, the technique of measurement is based on a null setting, so that it is capable of great accuracy in principle.

In §4, the method of standardising the potentiometer was described. In principle, there is no need to standardise the potentiometer, if the same potentiometer is used for setting the voltages \( b_r \) and for measuring the currents \( x_s \). This is so since the value of the current is obtained from a measurement of the voltage drop over a known resistance, so that both the voltage values \( (b_r) \) and the current values \( (x_s) \) are affected in the same proportion if the current through the potentiometer is different from the standard value. The equations (1) are still true, since the resistance values \( a_{rs} \) remain unchanged. Of course, this argument is valid only if the current through the potentiometer remains steady during the process of solving the equations.

However, if a dry battery is used for feeding the potentiometer, the e.m.f. may gradually fall during operation, thereby altering the current through the potentiometer. In such a case, it is necessary to keep the voltage across the ends of the potentiometer steady, by periodically standardising it against some reference voltage.

If a.c. is used, the need for standardisation can be completely eliminated provided the sources of e.m.f. for all the circuits are derived from the same primary source by means of transformers (see §5, below).

4. DETAILS OF THE MODEL II (FIG. 4)

(i) Description of the model

The components used for building Model II of the computer were almost similar to those of Model I. The 100 \( \Omega \) coefficient volume controls \( (a_{rs}) \) are mounted on the left hand side of the top panel (to the left of the galvanometer) and the sign switches for these coefficients are located on the right hand side. The toggle switch, at the top left of the galvanometer, is the one that is used for removing the shunt. The switch to the right of
this is the off-on switch for the voltage potentiometer. At the left of the lower panel are the on-off switches for the three current circuits and the plus-minus switches for currents $x_3$. Below these are seen the P-potentiometers $P_1$, $P_2$ and $P_3$ (with white knobs), for varying these currents.

The multipole setting switches for $b_r$ ($A_1$, $B_1$; $A_2$, $B_2$; $A_3$, $B_3$) are located on the right of the lower panel, along with their sign reversal switches.

The two knobs at the bottom are the setting switches A, B for measuring the currents $x_3$.

The selector switch $S$ is at the top middle of the lower panel. The galvanometer is brought to the Wheatstone's network in the first position of this switch (marked W) and in the second position (marked S) the galvanometer is brought to the standardising circuit. In the next three positions of this selector (marked 1, 2 and 3) the iterative steps are carried out.

The two-decade resistance box is fixed to the left-side of the computer. The 2 pole 9 way selector for bringing each of the nine $a_{rs}$ to the fourth arm of the Wheatstone's bridge and the variable resistance ($R'$) that controls the current through the voltage potentiometer are mounted on the right side of the computer (not seen in the photograph).

(ii) Auxiliary circuits

(a) Circuit for setting resistances.—The auxiliary circuits used in Model II were similar to those in Part I.

The same two-decade resistance box $R$ which is used for the potentiometer forms the third arm of the Wheatstone's network. A D.P.D.T. switch located on the right side of the instrument enables one to isolate this box from the Wheatstone’s network while it is being used as a potentiometer. When it is switched off, the two contacts $K_1$, $K_2$ in Fig. 5 (b) are broken. A 2 pole 9 way selector switch brings each one of the volume controls ($a_{rs}$) to the fourth arm of the Wheatstone's network. The galvanometer is brought to this network by turning selector $S$ to the position W.

(b) Standardisation of the potentiometer.—In the last section, it was mentioned that while using a dry battery, one should keep the current through the potentiometer constant. For this purpose, a standard Weston cell is connected across 101 $\Omega$ of the box, through the galvanometer, which may be done by bringing the selector switch to the position marked S. The variable resistance $R_1$ at the right side is adjusted for null reading of the galvanometer. The standardisation can be checked whenever necessary by bringing the selector $S$ to this second position (S).
(c) The sign switches.—The sign switches for affixing plus or minus signs to $x_i$, $b_r$ and $d_{rs}$ are exactly similar to those mentioned in Part I §4, (i).

(d) The equation selector.—The equation selector used is an 8 pole 8 way ganged switch. The function of this switch will well be understood from Fig. 5 (a). The terminals marked C, D, E, F, G, H, I and J are the 8 poles of the switch and $c_i$, $d_i$, $e_i$, $f_i$, $g_i$, $h_i$, $i_i$ and $j_i$ ($i = 1$ to 8) are the eight ways corresponding to each one of these poles.

For example, if this selector is set at the 4th position, since each pair of the poles (C, D), (E, F) and (I, J) are shorted, the points ($c_4$ and $d_4$), ($e_4$ and $f_4$) and ($i_4$ and $j_4$) will be connected respectively, and the galvanometer will be connected between the points $g_4$ and $h_4$.

It is easy to see from the figure that at each of the settings 3, 4 and 5 it connects up a particular row and also connects the galvanometer for balancing against the corresponding $b_r$. The iterative process is thus carried out in the 3rd, 4th and 5th positions of this switch (marked 1, 2, 3 in Fig. 4).

Fig. 5 (b) and 5 (c) show how the same galvanometer is brought to the Wheatstone’s network and to the standardising circuit, in the first and second positions respectively of the selector switch.

The 6th, 7th and 8th positions of this selector are used for reading off the currents $x_1$, $x_2$ and $x_3$ [Fig. 5 (d)].

(e) Current measurements.—A standard 100 $\Omega$ resistor is included in each one of the circuits and the ends of each one of these resistors can be brought for comparison against points A and B of the voltage potentiometer (R) successively, in the 6th, 7th and 8th positions of the selector [Fig. 5 (d)]. The switches A and B could then be adjusted each time for balance in the galvanometer and the current readily read off on the dials A and B.

(f) The galvanometer.—A 0–500 $\mu$A ammeter with a resistance of 100 $\Omega$ is used as the galvanometer with a shunt of 100 $\Omega$, which could be removed when needed by means of a switch. The sensitivity of this galvanometer was found to be sufficient to get an accuracy within 1%.

5. Operation with A.C.

As mentioned earlier, the arrangement described in this paper can be used with an alternating voltage supply which would replace all the batteries. Assuming that there is no inductive effect, there will not be any phase change introduced due to the current flow in the various circuits. If the source
of alternating voltage for the various circuits, including the potentiometric circuit, are derived from a number of secondaries of the same transformer, then the currents would all be either in phase or exactly out of phase according to the way in which they are connected to the secondary terminals. Therefore, if a commutator is incorporated in this circuit and it is reversed, the effect with a.c. is exactly equivalent to reversing the sign of the current with d.c. Consequently, all the arrangements used in the d.c. model for changing the sign of \( x_s, b_{rs} \) and \( a_{rs} \) can be adopted, without any further modification, for the a.c. model also.

The only component that needs a change is the null indicator which should be an a.c. galvanometer.
In testing out Model II, with a.c., a 0–100 µA meter with a germanium crystal rectifier was used as a null indicator and was found to serve the purpose very well. A step-down transformer with a number of secondary coils (220 V.–6·3 V.) was used as the source of current for the various circuits. Consequently the fluctuations in the mains voltage equally affect all the circuits, so that no errors are introduced. There is no need therefore, for standardisation. In practice, it was found that, even when heavy fluctuations of the order of 100 Volts in the input voltage (150–250 V.) were introduced artificially by using a Variac, the computer worked quite satisfactorily, viz., the balance point was not upset by such fluctuations.

Even though the wire wound potentiometers used were not strictly non-inductive, the error introduced was less than 1%. If one desires to have higher accuracy, it would be necessary to use non-inductive resistances, i.e., a good resistance box, for each coefficient $a_{rs}$. This would require $n^2$ resistance boxes, which would make the unit very costly (although it eliminates the need for a Wheatstone’s network). However, since only one row is connected up at a time, it is possible to devise an arrangement with only $n$ resistance boxes, by having a series of $n^2$ setting switches, similar to those used for setting the $n$ voltages $b_r$, from a single potentiometer. Such an arrangement is proposed to be built up and will be described in Part III. For this purpose an arrangement of resistances similar to the Kelvin-Varley potentiometer is required, rather than the ordinary two or three-decade resistance boxes.

6. MODIFICATION TO SOLVE SECULAR EQUATIONS

Of frequent occurrence in many fields is the problem of determining those values of a constant $\lambda$ for which non-trivial solutions exist to the homogeneous set of equations

\begin{align}
    a_{11}x_1 + \cdots + a_{1n}x_n &= \lambda x_1 \\
    a_{21}x_1 + \cdots + a_{2n}x_n &= \lambda x_2 \\
    \vdots & \quad \vdots \\
    a_{n1}x_1 + \cdots + a_{nn}x_n &= \lambda x_n
\end{align}

or, in matrix notation

$$AX = \lambda X$$

Such a problem is known as a characteristic value problem; values of $\lambda$ for which nontrivial solutions exist are called characteristic values (also eigenvalues or latent roots) of the problem. These values of $\lambda$ are also referred
to as the eigenvalues of the matrix A, i.e., the matrix composed of the coefficients $a_{rs}$. The corresponding vector solutions $X$ (having components $x_s$) are known as the characteristic vectors (or eigenvectors) of the problem or of the matrix A.

Equation (3) can also be written in the form

$$(A - \lambda I) X = 0 \quad (3a)$$

where $I$ is the unit matrix of order $n$. This homogeneous problem possesses nontrivial solutions if and only if the determinant of the coefficient matrix, i.e., $|A - \lambda I|$, vanishes or

$$|A - \lambda I| = 0 \quad (4)$$

Expanding this determinant, one finds that $\lambda$ is a root of an algebraic equation of degree $n$, known as the secular equation. The $n$ solutions $\lambda_1, \lambda_2, \ldots, \lambda_n$ which need not all be distinct, are the characteristic values or latent roots of the matrix A.

It is to be noted that if any one of these values of $\lambda$ are substituted in (2) and solved for $x_1, \ldots, x_n$ only $(n - 1)$ equations will be independent so that only $(n - 1)$ ratios are relevant to the problem.

A more general eigenvalue problem is to find the values of $\lambda$ which satisfy the matrix equation

$$AX = \lambda BX. \quad (5)$$

However this will not be discussed here.

Model II can easily be modified to obtain the eigenvalues of equation (2) by using an iterative method described by Frost and Tamres (1947). But it cannot readily be adapted to solve the more general type of equations (5). The various methods of solving equation (5) and their relative merits as far as they can be mechanised are reserved for Part III. Here the aim is to show that a simple modification of the circuit discussed above can be used to solve equations of the type (2).

We know that the left-hand side of equation (2) can be set up in analogy. If now this equation is rewritten in a slightly different form, viz.,

$$(a_{11} - \lambda)x_1 + \cdots + a_{1n}x_n = 0$$

$$a_{21}x_1 + \cdots + a_{2n}x_n = 0$$

$$\cdots$$

$$a_{n1}x_1 + \cdots + (a_{nn} - \lambda)x_n = 0\quad (6)$$
it will be seen how a circuit analogy of the complete equation can be set up. It is only necessary to have a method whereby the value of the resistances representing the diagonal terms \( a_{11}, \ldots, a_{nn} \) can all be decreased (algebraically) by the same magnitude.

This could conceivably be arranged by using ganged potentiometers for these resistances. In that case, one method of solving (3) will be to start with arbitrary values \( x_1 = 1, x_2, x_3, \ldots, x_n \) for the various currents and \( \lambda^{(0)} \) of \( \lambda \) and then to make use of the following iterative process (Frost and Tamres, 1947).

(i) Set up the first equation and change \( x_1^{(0)} \) to \( x_1^{(1)} \) for balance.

(ii) Set up the second equation and change \( x_3^{(0)} \) to \( x_3^{(1)} \) for balance.

(iii) Continue until the \((n-1)\)-th equation is set up and adjust the \( n \)-th variable \( x_n^{(0)} \) to \( x_n^{(1)} \) for balance.

(iv) Set up the \( n \)-th equation and adjust \( \lambda^{(0)} \) to \( \lambda^{(1)} \) for balance.

(v) Repeat the whole sequence until the quantities \( x_2, x_3, \ldots, x_n \), \( \lambda \) remain constant within the desired limits.

However it is difficult to gang potentiometers accurately and so a different method was adopted for Model II. In this method, an exact analogy of equation (2) is set up. Here the left-hand side is exactly the same as for the solution of simultaneous equations. On the right-hand side, however, we do not have the potentiometers giving voltages \( b_1, \ldots, b_n \) but a single potentiometer \( \lambda \) whose resistance can be set equal to \( \lambda \) and the current through which can be made equal to any required value from \( x_1 \) to \( x_n \). The latter adjustment can readily be made by incorporating a standard resistance \( r \) (100 \( \Omega \)) in series with the \( \lambda \)-potentiometer and comparing the voltage developed across this with an equal resistance \( r \) (100 \( \Omega \)) kept in series with each of the current circuits \( x_1 \) to \( x_n \) (Fig. 6 a) [the latter are already there in Model II, see §4, ii (e)]. However, it is not necessary to have a series resistance along with the \( \lambda \)-potentiometer; for one can tap off the required resistance \( r \) (100 \( \Omega \)) directly from the \( \lambda \)-potentiometer as shown in Fig. 6 (b), and bring it for comparison, so that equalisation of the current can be made. The advantage of having this arrangement is that the setting switch A–B (which is used for measuring the currents if the potentiometer is standardised) can directly be made to serve this purpose, provided it is adjusted to read the value \( r \) (100 \( \Omega \)). In order to set up the analogy of the right-hand side of all the equations (2), we need only a single potentiometer, through which the current flowing can be made different each time. So instead of having all the \( n \) \((A_n - B_n)\) setting switches any one setting switch (say \( A_1 - B_1 \))
may be chosen for the purpose, the current through which being made equal
to any one required value by the above method. Also, the value of \( \lambda \) can

![Diagrams](attachment:image.png)

*Fig. 6 (a) and 6 (b). Equalisation of current in \( \lambda \)-potentiometer.*

be directly read off on the dials. These arrangements are easily made, if
a slight modification is made in the connections to the selector switch \( S \),
shown in Fig. 5 (a). The modified circuit is shown in Fig. 7.

The terminals C, D, E, F, G, H, I and J are the 8 poles of the switch
and \( c_1, d_1, e_i, f_i, g_i, h_i, i_i \) and \( j_i \) \((i = 1 \text{ to } 8)\) are the 8 ways. We will now
see how the currents are equalised using this selector. Since C and D, E
and F, and I and J are shorted and the galvanometer is connected between
G and H, if the switch is set to the third position the points \( (c_3 \text{ and } d_3), (e_3
\text{ and } f_3), (i_3 \text{ and } j_3) \) are respectively connected and the galvanometer is intro-
duced between \( g_3 \) and \( h_3 \). This serves to make the current through the
\( \lambda \)-potentiometer equal to \( x_1 \), the current through the first circuit. Simi-
larly, at settings 5 and 7, one can make the current through the \( \lambda \)-potenti-
ometer equal to \( x_2 \) and \( x_3 \). At these same positions 3, 5 and 7, it is also
possible to measure the currents \( x_1, x_2, x_3 \) if the potentiometer is standardised.
Thus the following will be the sequence of operations that will have to be
made in order to solve equations (2) by the iterative process mentioned
above.

(a) **Selector is set in position 1.**—The coefficients \( a_{rs} \) are all fed in as
resistances using the Post Office Box arrangement and the signs of \( a_{rs} \) are
also set.

(b) **Selector is set in position 2.**—The potentiometer is standardised
by adjusting \( R_1 \) [as in §4, (ii)].
(c) **Selector is set in position 3.**—The current through the first circuit is measured by means of the setting switch A–B and adjusted to some standard value or unity (say $x_1$).

(d) The setting switch A–B is set to read 100 $\Omega$ and with selector in position 3, the variable resistance $R_1$ is adjusted for balance in the galvanometer. Thus the current $x_1$ is made to flow through the $\lambda$ potentiometer.

(e) The other variables $x_2$ and $x_3$ are represented as arbitrary currents $x_2^{(0)}$ and $x_3^{(0)}$ need not be measured and in any arbitrary value for $\lambda$, say $\lambda^{(0)}$ is set on the switch A$_1$–B$_1$.

(f) **Selector is set in position 4.**—Potentiometer $P_2$ is adjusted and $x_2^{(0)}$ is varied to $x_2^{(1)}$ for balance.

(g) **Selector is set in position 5.**—The variable resistance $R_1$ is adjusted for balance making $x_2^{(1)}$ to flow in the $\lambda$-potentiometer.

(h) **Selector is set in position 6.**—Potentiometer $P_3$ is adjusted and $x_3^{(0)}$ varied to $x_3^{(1)}$ for balance.

(i) **Selector is set in position 7.**—The variable resistance $R_1$ is adjusted for balance making $x_3^{(1)}$ to flow in the $\lambda$-potentiometer.

(j) **Selector is set in position 8.**—The setting switch A$_1$–B$_1$ is adjusted for balance to get a better value for $\lambda^{(0)}$, namely $\lambda^{(1)}$.

(k) The selector is now brought back to position 3 and $R_1$ is adjusted for balance in galvanometer, thus starting a new cycle of operations.

These cycles of operations are continued until the quantities $x_2$, $x_3$ and $\lambda$ remain constant within the desired limits. Then the values of $x_2$, $x_3$ are measured and $\lambda$ can be read off from the setting of the switch A$_1$–B$_1$.

This iterative method presents no difficulties in converging to the largest and smallest eigenvalues. Once these eigenvalues are obtained, it is possible in principle, to force the convergence upon some other value by keeping the trial vector $x$ orthogonal to both the largest and the smallest eigenvectors. But in practice, some difficulties in convergence to the intermediate eigenvalues may be encountered unless a good approximation is available to start with. This difficulty is felt even in numerical methods involving this particular iterative process. The method very largely depends on the experience of the computer and so automatic methods cannot be adopted (Murray, 1948). Fuller details on other iterative methods will be discussed in Part III.
The computer (Model II) can be present for solving simultaneous equations or for solving the secular equations by making use of a 6 pole 2 way switch $T$ (Fig. 8) (not seen in the photograph). When this switch is in its first way, it connects the points ($h_4$ and $A_1$), ($i_4$ and $B_1$), ($h_6$ and $A_2$), ($i_6$ and $B_2$), ($h_8$ and $A_3$), ($i_8$ and $B_3$) so that the computer can be used to solve simultaneous equations. When the switch $T$ is in the second way, the computer

![Diagram of modified circuit for secular equations](image)

**Fig. 7.** Modified circuit for secular equations.

![Diagram of T-switch sequence selector](image)

**Fig. 8.** The T-switch—sequence selector.
is ready for solving secular equation, since all the points \( h_4 \), \( h_6 \) and \( h_8 \) are connected to \( A_1 \), and \( j_4 \), \( j_6 \) and \( j_8 \) are connected to \( B_1 \), as shown in Fig. 8.

As a result of this modification, namely of the computer being able to solve either simultaneous equations or secular equations, the settings of the selector switch at which the iterative process for solving the former are made, are slightly different from those described in §4, ii (d). Instead of iterating in the settings 3, 4, 5 and measuring the currents \( x_s \) at 6, 7 and 8, iteration is now performed at settings 4, 6 and 8 and currents are measured at 3, 5 and 7.

The computer described here can handle only a third order secular equation. However there is no essential difficulty in constructing a larger computer based on these principles by making use of switches having larger capacity.

7. SUMMARY

This paper essentially deals with Model II of Lilāvatī (an analogue computer for solving linear simultaneous equations) where unlike in the first model, potentiometric methods are employed for measurements of current and voltage. The incorporation of the potentiometer has considerably simplified the number of operations required and has also helped in successfully modifying this computer to solve characteristic value problems. The operational details of this computer are also described in this paper.

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9. REFERENCES

Fig. 4. Lilavati—Model II