A New Application of Mohand Transform for Handling Abel's Integral Equation

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ABSTRACT: Abel's integral equation is an important singular integral equation and generally appears in many branches of sciences such as atomic scattering, mechanics, radio astronomy, physics, electron emission, X-ray radiography and seismology. In this paper, we give a new application of Mohand transform for handling Abel's integral equation and the complete procedure of handling Abel's integral equation using Mohand transform explain by giving some numerical applications in application section.

KEYWORDS: Abel's integral equation, Mohand transform, Inverse Mohand transform, Convolution theorem.

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I. INTRODUCTION: In 1823, Niels Henrik Abel discussed the motion of particle on smooth curve lying on a vertical plane using Abel's integral equation in mathematical form as [1-2]

$$f(x) = \int_0^x \frac{1}{\sqrt{x-t}} u(t)\, dt \quad (1)$$

Here the kernel of integral equation, $K(x,t) = \frac{1}{\sqrt{x-t}}$ becomes ∞ at $t = x$, the function $f(x)$ is known function and the function $u(t)$ is unknown function.

In the modern time, integral transforms are widely used mathematical techniques for solving advanced problems of science and engineering which mathematically express in terms of differential equations with constant or variable coefficients, partial differential equations with constant or variable coefficients, integral equations, partial integro-differential equations, integro-differential equations etc. Many researchers [3-30] applied different integral transforms (Laplace transform, Fourier transform, Hankel transform, Kamal transfom, Elzaki transform, Mohand transform, Aboodh transform, Sumudu transform, Wavelet transform etc) for solving many problems of science, engineering and daily life.

Mohand and Mahgoub [31] defined "Mohand transform'' of the function $F(t)$ for $t \geq 0$ in the year 2017 as

$$M\{F(t)\} = v^2 \int_0^\infty F(t) e^{-vt} dt = R(v), k_1 \leq v \leq k_2, \quad (2)$$

where the operator M is called the Mohand transform operator.

Sathya and Rajeswari [32] applied Mohand transform for solving linear partial integro-differential equations. Application of Mohand transform for solving linear Volterra integro-differential equations was given by Kumar et al. [33]. Aggarwal and Chaudhary [34] gave a comparative study of Mohand and Laplace transforms. Aggarwal et al. [35] defined Mohand transform of Bessel's functions. A comparative study of Mohand and Kamal transforms was given by Aggarwal et al. [36]. Aggarwal et al. [37] applied Mohand transform and solve the problems of population growth and decay. Aggarwal et al. [38] used Mohand transform for solving linear Volterra integral equations of second kind. Aggarwal et al. [39] gave a comparative study of Mohand and Elzaki transforms. A comparative study of Mohand and Aboodh transforms was given by Aggarwal and Chauhan [40]. A comparative study of Mohand and Sumudu transforms was given by Aggarwal and Sharma [41].

In this paper, we are giving a new application of Mohand transform for handling Abel's integral equation and explain all procedure by giving some numerical applications in application section.

II. SOME USEFUL PROPERTIES OF MOHAND TRANSFORM:

2.1 Linearity property [34, 36, 39-41]:

If Mohand transform of functions $F_1(t)$ and $F_2(t)$are$R_1(v)$and $R_2(v)$ respectively then Mohand transform of $[aF_1(t) + bF_2(t)]$ is given by $[aR_1(v) + bR_2(v)]$, where a, b are arbitrary constants.

2.2 Change of scale property [34, 36, 39-41]:

If Mohand transform of function $F(t)$ is $R(v)$ then Mohand transform of function $F(at)$is given by $aR\left(\frac{v}{a}\right)$.

2.3 Shifting property [36, 39-41]:

If Mohand transform of function $F(t)$ is $R(v)$ then Mohand transform of function $e^{at}F(t)$is given by

$\frac{v^2}{(v-a)^2}R(v-a)$.

2.4 Mohand transform of the derivatives of the function $F(t)$[34, 36, 39-41]:

If $M\{F(t)\} = R(v)$ then

a) $M\{F^{'}(t)\} = vR(v) - v^2F(0)$
b) $M\{F^{''}(t)\} = v^2R(v) - v^3F(0) - v^2F'(0)$
c) $M\{F^{(n)}(t)\} = v^nR(v) - v^{n+1}F(0) - v^nF'(0) - \cdots \ldots - v^2F^{(n-1)}(0)$

2.5 Convolution theorem for Mohand transforms [34, 36, 39-41]:

If Mohand transform of functions $F_1(t)$ and $F_2(t)$are$R_1(v)$and $R_2(v)$ respectively then Mohand transform of their convolution $F_1(t) * F_2(t)$ is given by

$$M\{F_1(t) * F_2(t)\} = \frac{1}{v^2}M\{F_1(t)\}M\{F_2(t)\}$$

$\Rightarrow M\{F_1(t) * F_2(t)\} = \frac{1}{v^2}R_1(v)R_2(v)$, where $F_1(t) * F_2(t)$ is defined by

$$F_1(t) * F_2(t) = \int_0^t F_1(t-x)\,F_2(x)dx = \int_0^t F_1(x)\,F_2(t-x)dx$$

III. MOHAND TRANSFORM OF FREQUENTLY ENCOUNTERED FUNCTIONS [34-36, 39-41]:

Table: 1

S.N.	$F(t)$	$M\{F(t)\} = R(v)$
1.	1	v
2.	t	1
3.	t^2	$\frac{2!}{v}$
4.	$t^n, n \in N$	$\frac{n!}{v^{n-1}}$
5.	$t^n, n > -1$	$\frac{\Gamma(n+1)}{v^{n-1}}$
6.	e^{at}	$\frac{v^2}{v-a}$

7.	$sinat$	$\frac{av^2}{(v^2+a^2)}$
8.	$cosat$	$\frac{v^3}{(v^2+a^2)}$
9.	$sinhat$	$\frac{av^2}{(v^2-a^2)}$
10.	$coshat$	$\frac{v^3}{(v^2-a^2)}$
11	$J_0(t)$	$\frac{v^2}{\sqrt{(1+v^2)}}$
12	$J_1(t)$	$v^2-\frac{v^3}{\sqrt{(1+v^2)}}$

IV. INVERSE MOHAND TRANSFORM [34, 36, 39-41]:

If $R(v)$is the Mohand transform of $F(t)$then $F(t)$is called the inverse Mohand transform of $R(v)$and in mathematical terms, it can be expressed as

$F(t) = M^{-1}\{R(v)\}$, where M^{-1} is an operator and it is called as inverse Mohand transform operator.

V. LINEARITY PROPERTY OF INVERSE MOHAND TRANSFORMS:

If $M^{-1}\{H(v)\} = F(t)$ and $M^{-1}\{I(v)\} = G(t)$ then

$M^{-1}\{aH(v) + bI(v)\} = aM^{-1}\{H(v)\} + bM^{-1}\{I(v)\}$

$\Rightarrow M^{-1}\{aH(v) + bI(v)\} = aF(t) + bG(t)$, where a, b are arbitrary constants.

VI. INVERSE MOHAND TRANSFORM OF FREQUENTLY ENCOUNTERED FUNCTIONS [34-36, 39-41]:

Table: 2

S.N.	$R(v)$	$F(t) = M^{-1}\{R(v)\}$
1.	v	1
2.	1	t
3.	$\frac{1}{v}$	$\frac{t^2}{2!}$
4.	$\frac{1}{v^{n-1}}$	$\frac{t^n}{n!}$
5.	$\frac{1}{v^{n-1}}$	$\frac{t^n}{\Gamma(n+1)}$
6.	$\frac{v^2}{v-a}$	e^{at}
7.	$\frac{v^2}{(v^2+a^2)}$	$\frac{sinat}{a}$

8.	$\frac{v^3}{(v^2+a^2)}$	$cosat$
9.	$\frac{v^2}{(v^2-a^2)}$	$\frac{sinhat}{a}$
10.	$\frac{v^3}{(v^2-a^2)}$	$coshat$
11.	$\frac{v^2}{\sqrt{(1+v^2)}}$	$J_0(t)$
12.	$v^2-\frac{v^3}{\sqrt{(1+v^2)}}$	$J_1(t)$

VII. MOHAND TRANSFORM FOR SOLVING ABEL'S INTEGRAL EQUATION: In this section, we present a new application of Mohand transform for handling Abel's integral equation.

Taking Mohand transform of both sides of (1), we have

$$M\{f(x)\} = M\left\{\int_0^x \frac{1}{\sqrt{x-t}} u(t)\,dt\right\}$$

$$\Rightarrow M\{f(x)\} = M\{x^{-1/2} * u(x)\} \qquad (3)$$

Applying convolution theorem of Mohand transform in (3), we have

$$M\{f(x)\} = \frac{1}{v^2} M\{x^{-1/2}\} M\{u(x)\}$$

$$\Rightarrow M\{f(x)\} = \frac{1}{v^2}\sqrt{\pi} v^{3/2} M\{u(x)\}$$

$$\Rightarrow M\{u(x)\} = \frac{v^{1/2}}{\sqrt{\pi}} M\{f(x)\}$$

$$\Rightarrow M\{u(x)\} = \frac{v}{\pi}\left[\frac{1}{v^2}\sqrt{\pi} v^{3/2} M\{f(x)\}\right]$$

$$\Rightarrow M\{u(x)\} = \frac{v}{\pi}\left[\frac{1}{v^2} M\{x^{-1/2}\} M\{f(x)\}\right]$$

$$\Rightarrow M\{u(x)\} = \frac{v}{\pi} M\{x^{-1/2} * f(x)\}$$

$$\Rightarrow M\{u(x)\} = \frac{v}{\pi}\left[M\left\{\int_0^x \frac{1}{\sqrt{x-t}} f(t)\,dt\right\}\right]$$

$$\Rightarrow M\{u(x)\} = \frac{v}{\pi} M\{F(x)\} \qquad (4)$$

where $F(x) = \int_0^x \frac{1}{\sqrt{x-t}} f(t)\,dt$ (5)

Now applying the property, Mohand transform of derivative of the function, on (5), we have

$$M\{F'(x)\} = vM\{F(x)\} - F(0)$$

$$\Rightarrow M\{F'(x)\} = vM\{F(x)\}$$

$$\Rightarrow M\{F(x)\} = \frac{1}{v} M\{F'(x)\} \tag{6}$$

Now from (4) and (6), we have

$$M\{u(x)\} = \frac{1}{\pi} M\{F'(x)\} \tag{7}$$

Applying inverse Mohand transform on both sides of (7), we get

$$u(x) = \frac{1}{\pi} F'(x) = \frac{1}{\pi} \frac{d}{dx} F(x) \tag{8}$$

Using (5) in (8), we have

$$u(x) = \frac{1}{\pi} \left[\frac{d}{dx} \int_0^x \frac{1}{\sqrt{x-t}} f(t)\, dt \right] \tag{9}$$

which is the required solution of (1).

VIII. APPLICATIONS: In this section, we present some numerical applications to explain the complete procedure of handling Abel's integral equation using Mohand transform.

8.1 Consider the Abel's integral equation:

$$x = \int_0^x \frac{1}{\sqrt{x-t}} u(t)\, dt \tag{10}$$

Taking Mohand transform of both sides of (10), we have

$$M\{x\} = M\left\{ \int_0^x \frac{1}{\sqrt{x-t}} u(t)\, dt \right\}$$

$$\Rightarrow 1 = M\{x^{-1/2} * u(x)\} \tag{11}$$

Applying convolution theorem of Mohand transform in (11), we have

$$1 = \frac{1}{v^2} M\{x^{-1/2}\} M\{u(x)\}$$

$$\Rightarrow 1 = \frac{1}{v^2} \sqrt{\pi} v^{3/2} M\{u(x)\}$$

$$\Rightarrow M\{u(x)\} = \frac{v^{1/2}}{\sqrt{\pi}} \tag{12}$$

Applying inverse Mohand transform on both sides of (12), we get

$$u(x) = \frac{1}{\sqrt{\pi}} M^{-1}\{v^{1/2}\}$$

$$\Rightarrow u(x) = \frac{2}{\pi} x^{1/2} \tag{13}$$

which is the required solution of (10).

8.2 Consider the Abel's integral equation:

$$1 + x + x^2 = \int_0^x \frac{1}{\sqrt{x-t}} u(t)\, dt \tag{14}$$

Taking Mohand transform of both sides of (14), we have

$$M\{1\} + M\{x\} + M\{x^2\} = M\left\{ \int_0^x \frac{1}{\sqrt{x-t}} u(t)\, dt \right\}$$

$$\Rightarrow v+1+\frac{2}{v}=M\{x^{-1/2}*u(x)\} \tag{15}$$

Applying convolution theorem of Mohand transform in (15), we have

$$v+1+\frac{2}{v}=\frac{1}{v^2}M\{x^{-1/2}\}M\{u(x)\}$$

$$\Rightarrow v+1+\frac{2}{v}=\frac{1}{v^2}\sqrt{\pi}v^{3/2}M\{u(x)\}$$

$$\Rightarrow M\{u(x)\}=\frac{1}{\sqrt{\pi}}\left[v^{3/2}+v^{1/2}+\frac{2}{v^{1/2}}\right] \tag{16}$$

Applying inverse Mohand transform on both sides of (16), we get

$$u(x)=\frac{1}{\sqrt{\pi}}M^{-1}\left\{v^{3/2}+v^{1/2}+\frac{2}{v^{1/2}}\right\}$$

$$\Rightarrow u(x)=\frac{1}{\sqrt{\pi}}\left[M^{-1}\{v^{3/2}\}+M^{-1}\{v^{1/2}\}+2M^{-1}\left\{\frac{1}{v^{1/2}}\right\}\right]$$

$$\Rightarrow u(x)=\frac{1}{\pi}\left[x^{-1/2}+2x^{1/2}+\frac{8}{3}x^{3/2}\right] \tag{17}$$

which is the required solution of (14).

8.3 Consider the Abel's integral equation:

$$3x^2=\int_0^x\frac{1}{\sqrt{x-t}}u(t)\,dt \tag{18}$$

Taking Mohand transform of both sides of (18), we have

$$3M\{x^2\}=M\left\{\int_0^x\frac{1}{\sqrt{x-t}}u(t)\,dt\right\}$$

$$\Rightarrow \frac{6}{v}=M\{x^{-1/2}*u(x)\} \tag{19}$$

Applying convolution theorem of Mohand transform in (19), we have

$$\frac{6}{v}=\frac{1}{v^2}M\{x^{-1/2}\}M\{u(x)\}$$

$$\Rightarrow \frac{6}{v}=\frac{1}{v^2}\sqrt{\pi}v^{3/2}M\{u(x)\}$$

$$\Rightarrow M\{u(x)\}=\frac{6}{v^{1/2}\sqrt{\pi}} \tag{20}$$

Applying inverse Mohand transform on both sides of (20), we get

$$u(x)=\frac{6}{\sqrt{\pi}}M^{-1}\left\{\frac{1}{v^{1/2}}\right\}$$

$$\Rightarrow u(x)=\frac{8}{\pi}x^{3/2} \tag{21}$$

which is the required solution of (18).

8.4 Consider the Abel's integral equation:

$$\frac{4}{3}x^{3/2}=\int_0^x\frac{1}{\sqrt{x-t}}u(t)\,dt \tag{22}$$

Taking Mohand transform of both sides of (22), we have

$$\frac{4}{3}M\{x^{3/2}\} = M\left\{\int_0^x \frac{1}{\sqrt{x-t}}u(t)\,dt\right\}$$

$$\Rightarrow \frac{\sqrt{\pi}}{v^{1/2}} = M\{x^{-1/2} * u(x)\} \qquad (23)$$

Applying convolution theorem of Mohand transform in (23), we have

$$\frac{\sqrt{\pi}}{v^{1/2}} = \frac{1}{v^2}M\{x^{-1/2}\}M\{u(x)\}$$

$$\Rightarrow \frac{\sqrt{\pi}}{v^{1/2}} = \frac{1}{v^2}\sqrt{\pi}v^{3/2}M\{u(x)\}$$

$$\Rightarrow M\{u(x)\} = 1 \qquad (24)$$

Applying inverse Mohand transform on both sides of (24), we get

$$u(x) = M^{-1}\{1\}$$

$$\Rightarrow u(x) = x \qquad (25)$$

which is the required solution of (22).

8.5 Consider the Abel's integral equation:

$$2\sqrt{x} + \frac{8}{3}x^{3/2} = \int_0^x \frac{1}{\sqrt{x-t}}u(t)\,dt \qquad (26)$$

Taking Mohand transform of both sides of (26), we have

$$2M\{x^{1/2}\} + \frac{8}{3}M\{x^{3/2}\} = M\left\{\int_0^x \frac{1}{\sqrt{x-t}}u(t)\,dt\right\}$$

$$\Rightarrow \sqrt{\pi}v^{1/2} + 2\frac{\sqrt{\pi}}{v^{1/2}} = M\{x^{-1/2} * u(x)\} \qquad (27)$$

Applying convolution theorem of Mohand transform in (27), we have

$$\sqrt{\pi}v^{1/2} + 2\frac{\sqrt{\pi}}{v^{1/2}} = \frac{1}{v^2}M\{x^{-1/2}\}M\{u(x)\}$$

$$\Rightarrow \sqrt{\pi}v^{1/2} + 2\frac{\sqrt{\pi}}{v^{1/2}} = \frac{1}{v^2}\sqrt{\pi}v^{3/2}M\{u(x)\}$$

$$\Rightarrow M\{u(x)\} = v + 2 \qquad (28)$$

Applying inverse Mohand transform on both sides of (28), we get

$$u(x) = M^{-1}\{v\} + 2M^{-1}\{1\}$$

$$\Rightarrow u(x) = 1 + 2x \qquad (29)$$

which is the required solution of (26).

8.6 Consider the Abel's integral equation:

$$\frac{3}{8}\pi x^2 = \int_0^x \frac{1}{\sqrt{x-t}}u(t)\,dt \qquad (30)$$

Taking Mohand transform of both sides of (30), we have

$$\frac{3}{8}\pi M\{x^2\} = M\left\{\int_0^x \frac{1}{\sqrt{x-t}}u(t)\,dt\right\}$$

$$\Rightarrow \frac{3}{4}\left(\frac{\pi}{v}\right) = M\{x^{-1/2} * u(x)\} \quad (31)$$

Applying convolution theorem of Mohand transform in (31), we have

$$\frac{3}{4}\left(\frac{\pi}{v}\right) = \frac{1}{v^2}M\{x^{-1/2}\}M\{u(x)\}$$

$$\Rightarrow \frac{3}{4}\left(\frac{\pi}{v}\right) = \frac{1}{v^2}\sqrt{\pi}v^{3/2}M\{u(x)\}$$

$$\Rightarrow M\{u(x)\} = \frac{3}{4}\sqrt{\pi}\frac{1}{v^{1/2}} \quad (32)$$

Applying inverse Mohand transform on both sides of (32), we get

$$u(x) = \frac{3}{4}\sqrt{\pi}M^{-1}\left\{\frac{1}{v^{1/2}}\right\}$$

$$\Rightarrow u(x) = x^{3/2} \quad (33)$$

which is the required solution of (30).

IX. CONCLUSION: In this paper, we have successfully discussed a new application of Mohand transform for handling Abel's integral equation. The given numerical applications in the application section explain the complete procedure for handling Abel's integral equation using Mohand transform. The results show that Mohand transform is a powerful integral transform for handling Abel's integral equation. In the future, Mohand transform can be used for solving other singular integral equations and their systems.

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