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Research Paper

Application of Iman Transform Method on Some Fractional Differential Equations

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Abstract
In the paper, we begin by introducing the origin of fractional calculus and the consequent application of the Iman transform on fractional derivatives. The Iman transformation may be used to solve mathematical problems without resorting to a new frequency domain. Once we establish this connection firmly in the general setting, we turn our attention to the application of the Iman transform method to some non-homogeneous fractional, ordinary differential equations. Ultimately, we acquire the graphical solution of the problem by using Matlab 2013a, developed by MathWorks

Key Words: *Iman Transform, Fractional Differential Equation, Linear and Non-linear, Initial Value Problem, Non-homogenous*

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I. Introduction

In the literature, there are many integral transforms being used in engineering and applied sciences. It is undoubtedly an effective tool for solving differential equations, integral equations. The fact that makes the integral transform so effective is that it can convert systems of differential equations and integral equations into algebraic equations.

Initially, the Iman transform was introduced by Iman [1] as a modification of the classical Sumudu Transform. The author [1-5] derived this transform for ordinary and partial derivatives. The main purpose of the presentation
of this paper is to demonstrate how applicable the Iman transform is in solving fractional differential equation.

II. Fundamental Properties of ITM and Fractional Calculus

In this section, we will shed light on some properties of Iman Transformation and Fractional Calculus.

2.1 Fundamental Facts of the Iman **Transformation Method**

The Iman transform of the function's belonging to a class B ,
Where

B=$\{f(t): \exists M, k1, k2>0$, such that $|f(t)|<Me^{\frac{|t|}{k_j}};\ t\in(-1)^j \times [0,\infty[\}$

, where f (t) is denoted by
$I[f(t)] = L(v)$and is defined [1, 2] as

$$I[f(t)] = \frac{1}{v^4}\int_0^\infty f\left(\frac{t}{v^2}\right)e^{-t}dt k1, k2 > 0 \qquad (1)$$

Or equivalently

$L(v) = \frac{1}{v^2}\int_0^\infty f(t)e^{-tv^2}dt \quad , \quad v \in (k1, k2)$ (2)

The following results can be obtained from the definition and simple calculations

(1) $\mathrm{I}[f'(t)] = v^2 L(v) - \frac{1}{v^2} f(0)$ (3)

(2) $\mathrm{I}[f''(t)] = v^4 L(v) - f(0) - \frac{1}{v^2} f'(0)$ (4)

(3) $\mathrm{I}[t\, f(t)] = \frac{1}{v^4}\frac{d}{dv}[v^2\, L(v)] - \frac{1}{v^2}[\, L(v)]$ (5)

(4) $\mathrm{I}[t^2\, f(t)] = \frac{1}{v^8}\frac{d^2}{dv^2}[v^2\, L(v)]$ (6

(5) $\mathrm{I}[t\, f'(t)] = \frac{1}{v^4}\frac{d}{dv}\left[v^2\, L(v) - \frac{1}{v^2} f(0)\right] - \frac{1}{v^2}\left[v^2\, L(v) - \frac{1}{v^2} f(0)\right]$(7)

(6) $\mathrm{I}[t^2 f'(t)] = \frac{1}{v^8}\frac{d^2}{dv^2}\left[v^2\, L(v) - \frac{1}{v^2} f(0)\right]$(8)

(7) $\mathrm{I}[t\, f''(t)] = \frac{1}{v^4}\frac{d}{dv}\left[v^4\, L(v) - f(0) - \frac{1}{v^2} f'(0)\right] - \frac{1}{v^2}\left[v^4\, L(v) - f(0) - \frac{1}{v^2} f'(0)\right]$(9)

(8) $\mathrm{I}[t^n] = n!\, \left[\frac{1}{v^2}\right]^{n+2}$(10)

2.2 Fundamental Facts of the Fractional Calculus:

Firstly, we mention some of the fundamental properties of the fractional calculus. Fractional derivatives as well as integral definition may different, but the most widely used definitions are those of Abel-Riemann [6].

Following the nomenclature in [7], a derivative of fractional order in the Abel-Riemann [6] is defined by

$$D^\alpha[f(t)] = \begin{cases} \frac{1}{\Gamma(m-\alpha)}\frac{d}{dt^m}\int_0^t \frac{f(\tau)}{(t-\tau)^{\alpha-m+1}}d\tau \ , & m-1<\alpha<m \\ \frac{d}{dt^m} f(t) \ , & \alpha = m \end{cases} \quad (11)$$

Where

$M \in Z^+$ and $\alpha \in R^+$ [6]. D^α Is a derivative operator here and

$D^{-\alpha}[f(t)] = \frac{1}{\Gamma(\alpha)}\int_0^t (t-\tau)^{\alpha-1} f(\tau)d\tau \ , t>0, \quad 0<\alpha\le 1$ (12)

On the other hand, according to Abel-Riemann, an integral of fractional order is defined by implementing the integration operator in the following manner

$J^\alpha[f(t)] = \frac{1}{\Gamma(\alpha)}\int_0^t (t-\tau)^{\alpha-1} f(\tau)d\tau \ , \ 0<\alpha$ (13)

When it come to some of the fundamental properties of fractional integration and fractional differentiation, then have been introduced to the literature by Podlubny [8]. Among these, we mention

$$J^{\alpha}[t^{n}] = \frac{\Gamma(1+n)}{\Gamma(1+n+\alpha)} t^{n+\alpha} \quad (14)$$

$$D^{\alpha}[t^{n}] = \frac{\Gamma(1+n)}{\Gamma(1+n-\alpha)} t^{n-\alpha} \quad (15)$$

Another main definition of the fractional derivative is that of Caputo [8, 9] who defined it by

$$^{c}D^{\alpha}[f(t)] = \begin{cases} \frac{1}{\Gamma(m-1)} \int_0^t \frac{f^{m}(\tau)}{(t-\tau)^{\alpha-m+1}} d\tau, & m-1 < \alpha < m \\ \frac{d}{dt^{m}} f(t), & \alpha = m \end{cases} \quad (16)$$

A fundamental fature of the Caputo fractional derivative [10] is that

$$J^{\alpha} cD^{\alpha}[\mathrm{f(t)}] = \mathrm{f(t)} - \sum_{k=0}^{\infty} f^{(k)}(0^{+}) \frac{t^{k}}{k!} \quad (18)$$

Theorem 1:
If $L(v)$is the Iman transformation of f(t), we knows that the Iman transformation of the derivatives with
integral order is given as follows [10]

$$\mathrm{I}\left[\frac{d}{dt} f(t)\right] = v^{2} L(v) - \frac{1}{v^{2}} f(0) \quad (19)$$

Proof:
Let us take the Iman transform [10] of f ′ = $\frac{d}{dt}f(t)$as follows

$$\mathrm{I}\left[\frac{d}{dt} f(t)\right] = \lim_{p\to\infty} \frac{1}{v^{2}} \int_0^p e^{-tv^{2}} \frac{d}{dt} f(t) dt$$

$$= \lim_{p\to\infty} \frac{1}{v^{2}} \left[e^{-tv^{2}} \int_0^p \frac{d}{dt} f(t) dt - \int_0^p e^{-tv^{2}} (-v^{2}) f(t) dt\right]$$

$$= \lim_{p\to\infty} \frac{1}{v^{2}} \left[e^{-tv^{2}} |f(t)|_0^p + v^{2} \int_0^p e^{-tv^{2}} f(t) dt\right]$$

$$= \lim_{p\to\infty} \frac{1}{v^{2}} \left[-f(0) + v^{4} \left\{\frac{1}{v^{2}} \int_0^p e^{-tv^{2}} f(t) dt\right\}\right]$$

$$= v^{2} L(v) - \frac{1}{v^{2}} f(0) \quad (20)$$

Equation (20) gives us the proof of theorem 1. When we continue in the same manner, we get the Iman transform of the second order derivative as follows [10];

$$\mathrm{I}\left[\frac{d^2}{dt^2}f(t)\right] = I\left[\frac{d}{dt}\left\{\frac{d}{dt}f(t)\right\}\right]$$

$$= \quad \mathrm{I}\left[\frac{d^2}{dt^2}f(t)\right] = v^2\,\mathrm{I}\left[\frac{d}{dt}f(t)\right] - \frac{1}{v^2}\frac{d}{dt}f(t)_{t=0}$$

$$= v^4L(v) - f(0) \;\; - \frac{1}{v^2}\frac{d}{dt}f(t)_{t=0} \qquad (21)$$

If we go on the same way, we get the Iman transform of the nth order derivative as follows:

$$L^n(\mathrm{v}) = \mathrm{I}\left[\frac{d^n}{dt^n}f(t)\right]$$

$$v^{-2n}\,L(v) - \sum_{k=0}^{n-1} v^{2n-2k-4}\,f^{(k)}(t)|_{t=0} \qquad for\;\; n\;\geq 1$$

Or

$$= \mathrm{I}\left[\frac{d^n}{dt^n}f(t)\right] = \; v^{2n}\left[L(v) - \sum_{k=0}^{n-1} v^{-2k-4}\;\frac{d^n}{dt^n}f(t)|_{t=0}\right] \qquad (22)$$

Theorem 2:
If $L(v)$is the Iman transformation of f (t), one can take into consideration the Iman transform of the Riemann-Liouville derivative as follow:

$I[D^\alpha$ [f(t)]=
$v^{2\alpha}\,[L(v) - \sum_{k=1}^{n} v^{-2\alpha+2k-4}\,D^{\alpha-k}f(t)|_{t=0}]$, $\quad -1< \mathrm{n} -1 \leq \alpha < \mathrm{n}$ (23)

Proof: Let us take the Laplace transformation off $'(t)$= $\frac{d}{dt}f(t)$

$$\ell[D^\alpha \text{ [f(t)]}$$

$$= S^\alpha\,T(s) - \sum_{k=1}^{n-1} S^k[D^{\alpha-k-1}f(t)|_{t=0}] \qquad (24)$$

$$= S^\alpha\,T(s) - \sum_{k=1}^{n} S^{k-1}[D^{\alpha-k}f(t)|_{t=0}]$$

$$= \; S^\alpha\,T(s) - \sum_{k=1}^{n} S^{k-2}[D^{\alpha-k}f(t)|_{t=0}]$$

$$= \; S^\alpha\,T(s) - \sum_{k=1}^{n} \frac{1}{S^{-k+2}}\,[D^{\alpha-k}f(t)|_{t=0}]$$

$$= \; S^\alpha\,T(s) - \sum_{k=1}^{n} \frac{1}{S^{\alpha-k+2-\alpha}}\,[D^{\alpha-k}f(t)|_{t=0}]$$

$$= \; S^\alpha\,T(s) - \sum_{k=1}^{n} S^\alpha\,\frac{1}{S^{\alpha-k+2}}\,[D^{\alpha-k}f(t)|_{t=0}]$$

$$\ell[D^{\alpha}\,[\mathrm{f(t)}] = S^{\alpha}\left[T(s) - \sum_{k=1}^{n}\left(\frac{1}{s}\right)^{\alpha-k+2}[D^{\alpha-k}f(t)|_{t=0}]\right] \tag{25}$$

Therefore, when we substitute v^2 for S , we get the Iman transformation of fractional order of f (t) as follows

$$I[D^{\alpha}\,[\mathrm{f(t)}] = v^{2\alpha}\,[L(v) - \sum_{k=1}^{n} v^{-2\alpha+2k-4}\,D^{\alpha-k}f(t)|_{t=0}] \tag{26}$$

III. Iman Transform Method on General Linear Fractional Differential Equation:

We will now apply ITM (Iman Transform Method) for solving Fractional Ordinary Differential Equations. We take into consideration a general linear ordinary differential equation with fractional order as follows:

$$\frac{\partial^{\alpha}V(t)}{\partial t^{\alpha}} = \frac{\partial^{2}V(t)}{\partial t^{2}} + \frac{\partial V(t)}{\partial t} + V(t) + C \tag{27}$$

Being subject to the initial condition

$$V(0) = f(0) \tag{28}$$

Then, we will obtain the analytical solutions of some of the fractional ordinary differential equation by using ITM. When we take the Iman Transformation of (27) under the terms of (22) and (26), we obtain the Iman transformation of (27) as follows

$$I\left[\frac{\partial^{\alpha}V(t)}{\partial t^{\alpha}}\right] = I\left[\frac{\partial^{2}V(t)}{\partial t^{2}}\right] + I\left[\frac{\partial V(t)}{\partial t}\right] + I[V(t)] + I[C]$$

$$v^{2n}\left[L(v) - \sum_{k=0}^{n-1} v^{-2k-4}\,\frac{d^n}{dt^n}f(t)|_{t=0}\right] =$$

$$v^{4}L(v) - f(0) \quad - \frac{1}{v^2}\frac{d}{dt}f(t)|_{t=0} + v^{2}L(v) - \frac{1}{v^2}f(0) \quad + L(v) \quad + C$$

Then we have

$$L(v)[1 - v^{4-2\alpha} - v^{2-2\alpha} - v^{-2\alpha}] = t(v) - v^{-2\alpha}V(0) - v^{-2-2\alpha}V(0) + v^{\alpha}C \tag{29}$$

$$L(v) = \frac{1}{[1 - v^{4-2\alpha} - v^{2-2\alpha} - v^{-2\alpha}]}[t(v) - v^{-2\alpha}V(0) - v^{-2-2\alpha}V(0) + v^{\alpha}C]$$

Where t(v)is defined by

$$\sum_{k=1}^{n} v^{-2\alpha+2k-4} \; [D^{\alpha-k}\, V(t)|_{t=0}] - v^{-2\alpha+2k-4}\, \frac{\partial V(t)}{\partial t}|_{t=0}$$

. When we take the inverse Iman
transformation of (29) by using the inverse transform table in [1-5], we get the solution of (27) by using ITM as follows:

$$V(t) = I^{-1}\left[\frac{1}{[1 - v^{4-2\alpha} - v^{2-2\alpha} - v^{-2\alpha}]}[t(v) - v^{-2\alpha}V(0) - v^{-2-2\alpha}V(0) + v^{\alpha}C]\right] \quad (30)$$

IV. Applications of ITM to Non-homogeneous Fractional Ordinary Differential Equation's:

In this section, we have applied Iman Transform Method to the non-homogeneous fractional ordinary differential equations as follows:

Example 1: Firstly, we consider the non-homogeneous fractional ordinary differential equation as follows [12]

$$[D^{\alpha}\,[\mathrm{V(t)}] = -V(t) + \frac{2}{\Gamma(3-\alpha)}t^{2-\alpha} - \frac{1}{\Gamma(2-\alpha)}t^{1-\alpha} + t^2 - t, t > 0, 0 < \alpha \le 1 \quad (31)$$

With the initial condition being V(0)= 0 (32)

In order to solve (31) by using ITM, when we take the Iman transform of both sides of (31), we get the Iman transform of (31) as follows:

$$I[D^{\alpha}\,[\mathrm{V(t)}] + V(t)] = I\left[\frac{2}{\Gamma(3-\alpha)}t^{2-\alpha} - \frac{1}{\Gamma(2-\alpha)}t^{1-\alpha} + t^2 - t\right] \quad (33)$$

$$I[D^{\alpha}\,[\mathrm{V(t)}] + V(t)] = I\left[\frac{2}{\Gamma(3-\alpha)}t^{2-\alpha}\right] - I\left[\frac{1}{\Gamma(2-\alpha)}t^{1-\alpha}\right] + I[t^2] - I[t]$$

$$I[D^{\alpha}\,[\mathrm{V(t)}] + V(t)] = \frac{2}{\Gamma(3-\alpha)}I[t^{2-\alpha}] - \frac{1}{\Gamma(2-\alpha)}I[t^{1-\alpha}] + I[t^2] - I[t]$$

$$[v^{-2\alpha} + 1]L(v) = 2v^{2\alpha-8} - v^{2\alpha-6} + 2v^{-8} - v^{-6}$$

$$[1 + v^{2\alpha}]L(v) = 2v^{-8} - v^{-6} + 2v^{-8-2\alpha} - v^{-6-2\alpha}$$

$$L(v) = 2v^{-8} - v^{-6} \quad (34)$$

When we take the inverse Iman Transform of (34), we get the analytical solution of (31) by ITM as follows:

$$I[\,[\mathrm{V(t)}]] = 2v^{-8} - v^{-6}$$

$$\mathrm{V(t)} = t^2 - t \quad (35)$$

If we take the corresponding values for some parameters into consideration, then the solution of (31) is in full agreement with the solution mentioned in [14].

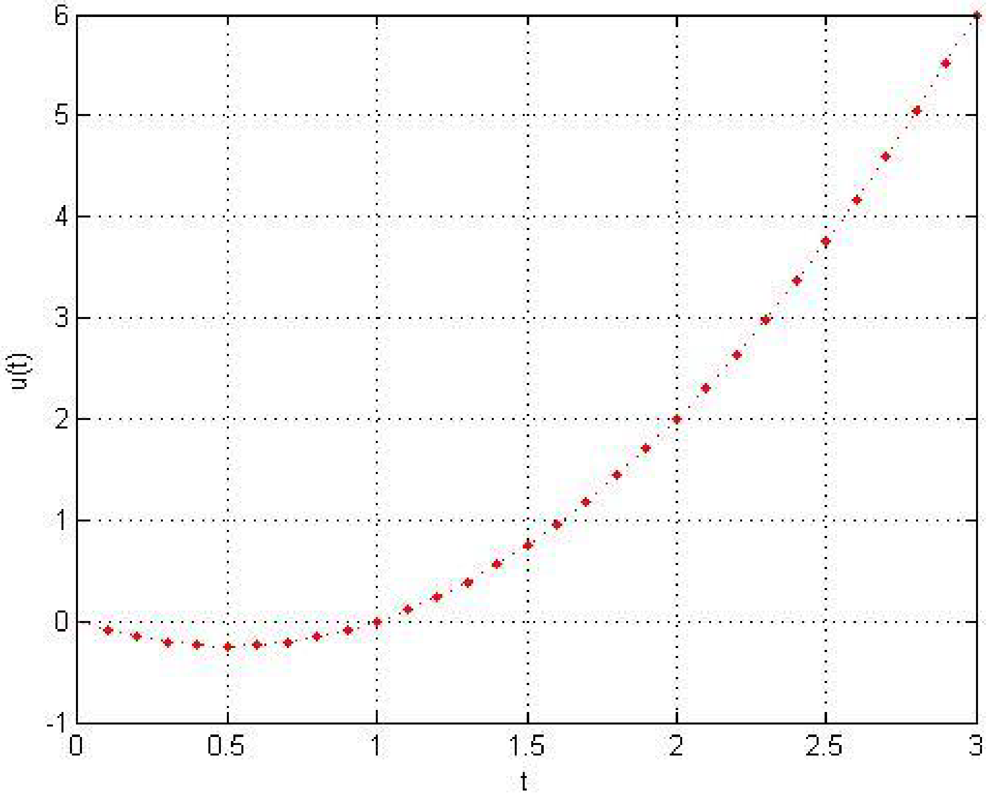

Fig 1: Analytical solution by Iman transform method of Example 1

Example 2:
Firstly, we consider the non-homogeneous fractional ordinary differential equation as follows [12]:

$$[D^{0.5}\ [\mathrm{V(t)}]] + V(t) = t^2 + \frac{\Gamma(3)}{\Gamma(2.5)} t^{1.5}; \qquad t > 0 \qquad (36)$$

With the initial condition being U(0)= 0 (37)

In order to solve (36) by using ITM, when we take the Iman transform of both sides of (36), we get the Iman transform of (36) as follows:

$$I[D^{0.5}\mathrm{V(t)}] + I[\mathrm{V(t)}] = I[t^2] + \frac{\Gamma(3)}{\Gamma(2.5)} I[t^{1.5}]$$

$$I[D^{0.5}\mathrm{V(t)}] + I[\mathrm{V(t)}] = I[t^2] + 1.5045\ I[t^{1.5}]$$

$$L(v) = 2v^{-8} \qquad (38)$$

When we take the inverse ImanTransform of (38) by the inverse transform table, we get the analytical solution of (36) by using ITM as follows:

$$L(v) = I[\,[\mathrm{V(t)}]] = 2v^{-8}$$

$\mathrm{V(t)} = t^2$ (39)

The solution (39) obtained by using the Iman transform method for (36) has been checked by the Matlab .

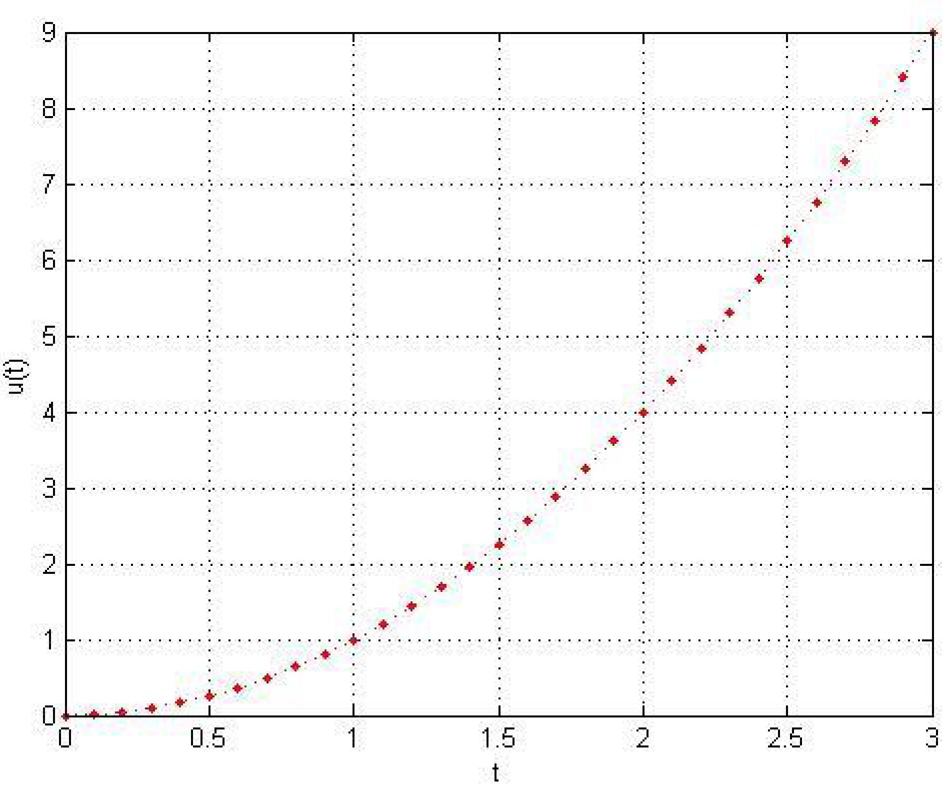

Fig 2: Analytical solution by Iman transform method of Example 2

IV. Concluding Remarks

Various methods have been developed, preceding this study, in order to derive approximate solutions to a number of fractional differential equations. In the course of this paper, non-homogeneous, fractional and ordinary differential equations have been addressed and solved by using the Iman transform after yielding related formulae for fractional integrals, derivatives, and the Iman transform of Fractional Ordinary Differential Equations. The Iman technique may be applied to solve multiple types of problems, such as initial-value problems and boundary-value problems in applied sciences, engineering fields, mathematical physics, and aerospace sciences. In consequence, this newly hatched approach has been implemented successfully on fractional ordinary differential equations, which proves to be interesting. As such and practically so, it augments the library of integral transform approaches. There remains little doubt, based on our findings demonstrated in Figures 1 and 2, that the ITM technique remains a direct, strong and valuable tool for the solution of same fractional differential equations.

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Table of Functions and their Iman Transform

$f(t)$	$I[f(t)] = F(v)$
1	$\frac{1}{v^4}$
t	$\frac{1}{v^6}$
	$\frac{2!}{v^8}$

$t^n n \in N$	$\frac{n!}{\boldsymbol{v^{2n+4}}}$
e^{at}	$\frac{\mathbf{1}}{\boldsymbol{v^2(v^2-a)}}$
$\sin(at)$	$\frac{\boldsymbol{a}}{\boldsymbol{v^2(v^4+a^2)}}$
$\cos(at)$	$\frac{\mathbf{1}}{\boldsymbol{v^4+a^2}}$
$H(t-a)$	$\frac{\mathbf{1}}{\boldsymbol{v^4}} e^{-av^2}$
$\delta(t-a)$	$\frac{\mathbf{1}}{\boldsymbol{v^2}} e^{-av^2}$
$\sinh(at)$	$\frac{\boldsymbol{a}}{\boldsymbol{v^2(v^4-a^2)}}$
$\cosh(at)$	$\frac{\boldsymbol{a}}{\boldsymbol{v^4-a^2}}$
$t^{a-1}/\Gamma(a)$, a>0	$\left(\frac{\mathbf{1}}{\boldsymbol{v^2}}\right)^{\boldsymbol{a+1}}$